# SECRETS OF THE SUBMARINE

U. S. SUBMARINE NARWHAL RUNNING ON SURFACE AT REDUCED SPEED

# SECRETS OF THE SUBMARINE

BY

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*WITH ILLUSTRATIONS FROM PHOTOGRAPHS*

NEW YORK
DODD, MEAD AND COMPANY
1917

Letter from Admiral Henry T. Mayo, U. S. N., Commander-in-Chief of the United States Atlantic Fleet to the author.

UNITED STATES ATLANTIC FLEET,
U. S. S. Pennsylvania, Flagship

My dear Hay:

I have heard with much interest of your intention to write and publish a book at this time dealing, in non-technical language, with the vitally interesting subject of the Submarine and explaining the general principles of its complicated mechanism in terms that the general public can readily understand.

I agree with your opinion that such a book will find popular interest under the present circumstances and the fact that it is written by a person who has devoted his time exclusively to the design and construction of these vessels for the past seventeen years, both here and abroad, will give the book a character of authenticity that must strongly appeal to the intelligent reader.

I shall look forward with much pleasure to receiving the promised copy when it is finished.

Very sincerely yours,
H. T. MAYO.

## FOREWORD

In writing the following treatise on the subject of the submarine, the author has endeavoured to submit to the general reading public, in entirely nontechnical language, a comprehensive but brief summary, stripped of all unnecessary detail, of the salient characteristics of the present day submarine, its limitations and immediate possibilities, and an analysis of popular misconceptions, all in especial reference to the rôle the submarine has played in the present war and is likely to play before the war is concluded. To some readers with possibly more or less technical knowledge, certain portions of this book may appear unnecessarily elementary and superfluous—more suitable for the school boy than the adult, and such portions will be read with impatience, if at all. To those critics it can only be said that no question has been discussed throughout the book which has not been repeatedly propounded to the author, and in every case by persons of

education and unquestioned intelligence at least in some branch of knowledge if not in this particular one.

Several books have already been published dealing miscroscopically with the historical development of submarines from diving-bell days onward; other books treating the purely technical aspects of the subject have likewise appeared, but, so far as the author has been able to ascertain, no book has hitherto been written which has attempted, for the benefit of the general public and in language which all could understand, to dissect the weapon which, at this intensely interesting moment in the history of the world, seems to hold the fate of the future in suspense.

In a conversation with the Father of Ruthlessness, Admiral von Tirpitz, as late as the year 1911, the latter remarked that he was not at all certain that submarines were an essential part of Germany's naval programme. The author tried to convince him to the contrary. To-day, perhaps, it is just as well for us all that he did not succeed. Possibly this book will explain why von Tirpitz has since changed his mind.

Whatever other merit may attach to the information submitted herein, the chief claim to consideration and authenticity is derived primarily from the fact that it is the only book on this subject written by one whose profession it is to design and construct submarines and who, for the past seventeen years, has been in daily touch with every phase of their development not alone in this country but also and more especially in Europe.

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## CHAPTER I

### Antecedents of the Submarine

In discussing the history of the submarine, the question has often been asked, "Who was the inventor of the submarine?" This might more properly be changed to, "Who were the inventors of the submarine?" It is undoubtedly correct to assume that when first attempts were made in the early part of the seventeenth century by the Dutchman Cornelius van Drebbel, it was with the idea in mind of improving upon the primitive diving-bell and providing it with some means of locomotion that the rudimentary submarine was evolved. In the case of the diving-bell the bottom was open and the air trapped in the upper part of the bell was compressed by the pressure of the water, the pres-

sure depending upon the depth to which the bell was lowered. Van Drebbel's submarine was a casing constructed of wood and covered with leather, which was hermetically sealed when submerged so that the navigator was not subjected to the pressure of the water, and the depth to which the vessel could go was limited only by the strength of the casing to resist crushing, and not by the physical ability of the navigator to resist the pressure of the air, as in the case of the diving-bell. The means of propulsion consisted of two oars projecting through the sides, a water-tight joint being made with leather glands. Rising and submerging as well as propulsion were effected by the oars with which the device was fitted.

About one hundred and fifty years later David Bushnell, an American, developed an improvement on van Drebbel's idea. Bushnell's submarine was likewise a one-man affair, but was propelled more scientifically by a hand gear inside the boat operating a propeller at the stern. A tank was fitted in the bottom of the vessel to contain ballast water and steering in the horizontal plane was accomplished by means of an ordinary rudder. This vessel was in-

tended for naval purposes and carried externally a sort of portable mine which could be attached, by means of a long screw operated from inside the boat, to the hull of an enemy vessel. The attachment of the mine once accomplished the submarine discreetly retired to a safe distance and the explosion of the mine was brought about by clock-work.

Although several attempts were made under war conditions to attack British war ships anchored in New York Harbour, they ended in failure as far as the damage done to the enemy was concerned because of the impracticability of the armament system. The difficulty of exactly locating the enemy vessel in coming up under it and the difficulty of causing the screw to penetrate the copper sheathing of the hull, discredited the military usefulness of Bushnell's boat, although it had given ample evidence of its manœuvering possibilities.

Shortly thereafter Robert Fulton, whose claim to fame rests upon his invention of the steamboat, devoted his attention to the development of submarines. He laid his plans before the naval authorities in America, but meeting with very little encouragement he then took up

the matter with the French Government and an experimental vessel was built which differed from Bushnell's submarine principally in its shape. The Bushnell submarine was built in the shape of an ordinary buoy but the Fulton vessel, although it was also a one-man affair, was a horizontal cylinder with pointed ends, more nearly resembling the later designs of John P. Holland.

Between 1865 and 1875, several individuals working in different parts of the world were experimenting with variations upon this theme, among whom may be mentioned Mr. Nordenfelt, a Swedish engineer; Mr. Bauer, a German mechanic; Mr. John P. Holland, an Irishman living in America, and M. Laubeuf, a French naval constructor. Among those mentioned, the two who attained most conspicuous success were undoubtedly Holland and Laubeuf, and it is a fact that the fundamantal ideas of their later designs were inspired by the success which had been attained by Robert H. Whitehead with the automobile torpedo. In fact, all of the principles involved in the operation of the Whitehead torpedo were embodied in the Holland and Laubeuf designs and in the subsequent off-

shoots from those designs. It has been claimed that the development of the storage battery has likewise been responsible for the rapid advance that was made at that time in the science of submarine invention. I think it would be equally true to say that the rapid progress in submarine development at that time stimulated to a large degree scientific interest in the development of the storage battery. I think it may safely be said that those who are chiefly responsible for the modern submarine are Robert Whitehead, John P. Holland and M. Laubeuf, although it is, of course, equally true that in their efforts they had the benefit of the experience of those who had gone before them and they were largely assisted by the parallel progress that had taken place in other departments of science and engineering. At a later date Mr. Simon Lake, an American, interested himself in the development of a submarine that was primarily intended for salvage purposes, but has since been diverted by force of circumstances into the less picturesque but more necessary uses of naval warfare.

# CHAPTER II

## Elements of Design and Construction of Modern Submarines—Hull

### DIFFERENTIATION OF TYPES

All submarines of the present day may be classified broadly as single hull or double hull or a combination of the two. Single hull vessels are essentially those, as the name would indicate, having only a single shell, which has to be constructed of sufficient strength to withstand the pressure of submergence. This necessitates a cross-section of circular or approximately circular form, which is tapered at both ends to reduce resistance to propulsion and is generically described as spindle-shaped or cigar-shaped. In later designs of this type the form of the bow and stern has been somewhat modified to improve the sea-going qualities. Mr. Holland was the exponent of the single hull type and it is this system which is being used almost exclusively in the American, English,

Spanish and Japanese Navies, and to a limited extent in some other navies. The double hull type, of which M. Laubeuf may be considered the exponent, consists of a cylindrical hull with flat ends, of sufficient strength to withstand the pressure of submergence, entirely encased in an outer hull of thin plating to give the vessel a ship-shape form to reduce resistance and improve the sea-going qualities when navigating on the surface. This type is now used practically exclusively in the French, Austrian and German Navies, the last named, now known as the Krupp-Germania type, having been evolved from plans sold to Krupp by a French engineer named d'Equevilley.

The composite type, which consists of a combination of the two foregoing types, certain parts of the vessel being of single hull construction and other parts of double hull construction, are used by the Italian, Portuguese and Brazilian Navies from the designs of an Italian engineer, Sig. Laurenti, associated with the Fiat Co., and by Holland and Denmark from the designs of the writer. In practically every navy, designs of other types than those mentioned here-

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The inherent difference between the single hull and the double hull type is essentially a question of stability and will be discussed in the section relating thereto.

There is a tendency, however, in modern naval practice to group submarines in two general classes, quite independent of any constructional difference in type. These classes are known generally as coastal submarines and fleet submarines. The coastal submarines generally do not exceed 600 tons in displacement and in the Dutch Navy are as small as 150 tons. They are utilised for the local defence of harbour and coast, having their base at some suitable shore station from which they can readily replenish their supplies. The fleet submarines, which are intended to accompany the battle fleet in offensive operations, are necessarily much larger and have a much higher speed. They are intended to keep the sea under any conditions of wind and weather for a period of three to four weeks. There is considerable divergence of opinion as to the size they should be, but they are seldom less than 1,000 tons' displacement. In the American Navy three experimental fleet submarines of 1,200 tons' displacement are

under construction, and in some foreign navies experimental vessels of nearly 2,000 tons' displacement are being built; but it may safely be said that 95% of the submarines now in service in all navies do not exceed 900 tons' displacement.

Another point which is nearly as controversial as the submarine versus the submersible question, is that of the "even keel" versus the "diving" type. In theory, the even keel type is fitted with rudders which, for the sake of distinction, are called hydroplanes, situated about one-fourth of the length from the bow and stern. By the parallel operation of these rudders, the submergence of a vessel is intended to be accomplished on an even keel. That is to say, the axis of the vessel remains horizontal and parallel with the surface of the water during the operation of submergence. On the other hand, the diving type was originally fitted with horizontal (or diving) rudders at the stern only and by their operation produced an inclination in the axis of the boat and caused it literally to dive to the desired depth, the reverse operation being employed to bring it to the surface. As development in size took place,

it was found by practical experience that the vessel became unwieldy and rudders were fitted in the bow to facilitate the operation of diving. At the same time, practical experience also showed the advisability of fitting stern rudders on boats of the even keel type. In fact, practical experience has proven that the even keel type can only be made to submerge readily when the axis of the boat is slightly inclined, and improvements in the diving type have made it possible to submerge with a very small angle of inclination, so that the distinction between even keel boats and diving boats is more artificial than real and can be relegated to the same category as the hair splitting over "submarines" and "submersibles."

### CHOICE OF TYPE

Another question that has frequently been put is, "What is the best type?" In reply it can only be said that there is no definite answer to that question. It is largely a matter of personal opinion and taste among experts, and there are even more opinions than there are types. There is, of course, a tendency on the part of all governments to adopt the type which

is indigenous to its own soil, i. e., one that has been developed to its present point of perfection by a citizen of the country in question, and the naval boards who are responsible for the compilation of their requirements and specifications endeavour thereby to mould the design into some degree of conformity with the exigencies of their naval policy.

The United States has confined itself, with one exception, exclusively to the designs of Holland and Lake, both American citizens. France has followed the general characteristics of Laubeuf's original design. Italy has built all of her submarines in accordance with the designs of an Italian engineer, Sig. Laurenti, and Russia, although she has built several others types, has also patronised largely the designs of Bubnoff, a Russian naval officer. The English submarines, although originally built from Holland designs, have now so far departed from their former characteristics that they can more accurately be called, as indeed they are, Vickers-Admiralty design, and the German and Austrian submarines have been developed by Krupp from an original French design. The only other design from which submarines have

been built and are actually in servi
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power.

During the last few months it has
been contended that German subma
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evidence of that fact the many perfo
German submarines that have fille
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the intention in this book to discuss t
merits of different types, it can sa
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ten that the Allies are obliged to maintain their over-seas traffic and this necessarily supplies a goodly quantity of easy targets for German submarines, whereas the seas are utterly cleared of German ships and allied submarines can scour the ocean in vain for anything at which to shoot. Where there has been an occasional opportunity for a British or French submarine to accomplish something, the work done has been no less brilliant, if somewhat less spectacular, than the destruction the German submarines have caused. The success of a British submarine in penetrating all the defences of the Dardanelles and entering the sea of Marmora, has already been published, and it is likewise a fact that British submarines have penetrated the German mine field right up to the entrance to Wilhelmshaven and have been within torpedo range of German warships lying there at anchor. Why were these warships not torpedoed? Because each and every one was surrounded by a shoal of small vessels from which a perfect net-work of cables, chains and nets descended to the bottom, constituting an impenetrable wall against torpedo fire.

The value of any type, as such, depends, how-

ever, not alone on design, but equally upon the quality of workmanship and material employed. In the latter respects, German submarines certainly rank high, and that factor would go a long way to explain their efficiency in keeping the sea for long periods of time. One of the most prominent shipbuilding engineers in the United States told me recently that he did not believe American workmen were *capable* of working with the same degree of accuracy as German or, in fact, any high-class European workmen. This was especially in reference to the Diesel engines, in the construction of which a high degree of accuracy is requisite. I hope for the sake of the submarine future of the United States that this sweeping indictment, although made by an eminent and undoubted authority on the subject, is not to be taken too pessimistically.

There is, however, still another element which contributes materially to the success of a submarine, quite regardless of type, and in that particular respect certainly Germany, and probably all the belligerent powers, have a considerable advantage over any other power not engaged in the present hostilities. That is, in

the possession of submarine commanders and crews who have been through long months of experience under actual war conditions. The disappointment of those who suppose that the efficiency of belligerent submarines can be paralleled by constructing vessels of the same type will synchronise with their realisation of the above fact.

Having decided upon a particular type, which, as already explained, is a decision that is usually arrived at by taking the majority opinion of the conflicting views of a board of naval experts, among whom the question of nationality of the inventor has considerable weight, and the type that first obtained a foothold has at least equal consideration, the question of drawing up specifications in such a way as to give the best combination of military qualities upon any given displacement has then to be decided. This is a much more complicated matter than deciding the same characteristics for a battleship or any other type of war vessel. In an ordinary vessel which navigates only on the surface of the sea, the major questions of armament, speed and radius of action demand initial consideration. In the case of

the submarine, not alone these three factors but two additional factors immediately appear, viz., speed and radius of action submerged. These five conflicting factors, none of which can be unduly enhanced without detracting from one or more of the others, must be so apportioned that the maximum of military efficiency is attained. This varies greatly with different powers. In some cases high speed on the surface is considered of prime importance; in other cases high speed submerged, entailing a comparatively low surface speed, is the desideratum. Another factor which forms an important element in the design, and which has not yet been mentioned, is safety. There is wide divergence of opinion in different navies as to the amount of weight and space that should be devoted to safety arrangements, and there are submarines in commission to-day which exemplify both extremes. In certain navies, where "safety first" seems to be a sine qua non, at least as far as their submarines are concerned, there are examples of vessels in commission in which the total amount of weight devoted to safety arrangements exceeds the weight of the main engines and is three times as much as the

U. S. SUBMARINE L-1, HAMPTON ROADS

total weight devoted to armament. From this extreme we have every possible variation down the scale to the submarine that has been built on the principle that it's a dangerous thing anyway and sure to sink in case of accident, so why waste any space or weight at the expense of military efficiency in useless devices for attempting to save the doomed boat and crew. There is undoubtedly a happy medium in this respect that will be dealt with in the section relating to safety devices.

### TANK SYSTEM

A submarine is a vessel that must be capable of navigating on the surface under practically the same conditions as an ordinary ship, and at the same time must be capable of total submergence, in water of any degree of salinity. To overcome the buoyancy of the vessel when floating in what is commonly known as the surface condition, it has been the practice since the earliest days of submarine navigation to take on weight by admitting sea-water into tanks constructed for that purpose and of sufficient size, so that when entirely full, the buoyancy is

practically destroyed and the vessel is on the point of sinking. When the vessel is in the latter condition it is said to be in "diving trim," i. e., still on the surface but ready to dive. The act of complete submergence can only be accomplished when the vessel is under way.

The diving rudders or hydroplanes which fulfil the same function as ordinary steering rudders, except that they are horizontal instead of vertical, are employed to steer the vessel on its course below the surface. In the same sense that an ordinary ship answers its helm only after it has attained a certain speed, which is technically called "steerage way," so in the submarine it is only possible for the diving rudders or hydroplanes to effect submergence when the vessel has attained a speed of about four knots. Once the vessel is under the control of the diving rudders, it is clear that by the operation of these rudders she can be steered to any depth below the surface within the limits of safety that it is desired to navigate.

The capacity of the water-ballast tank or tanks used to destroy the buoyancy of the vessel when in the surface condition amounts to about 25% of the total displacement, and is

equal to what is generally called the "reserve buoyancy."

In the single hull type, the tanks which contain this water ballast are built into the interior of the vessel, whereas in the double hull type the space between the inner and outer hulls constitutes the water ballast tanks. The exact size, shape and position of these tanks constitute one of the most exact features of a very exact science. The position must be such that when the tanks are entirely filled, the boat will float horizontally. When the tanks are entirely full and the boat is in diving trim, the longitudinal stability is very small, so that a slight miscalculation in the position of the ballast tanks would cause the boat to float at an impossible angle. One speaks of tanks because in practice it is found necessary to subdivide the water ballast space into as many as perhaps a dozen different compartments to prevent the wash of the water inside while they are being filled, with the consequent loss in stability. It is, of course, essential that the tanks, when the vessel is in diving trim, should be completely full for the same reason.

The fact, however, that the tanks must be

completely full adds very seriously to the constructor's difficulties. It will be realised that in designing such a vessel the amount of weight that can be allotted to each of the several parts must first be determined upon, and the weight allowed for water ballast is as fixed and definite an item as any other. Now in building an ordinary ship, if the actual vessel exceeds the calculated weight, which, as every shipbuilder knows, is invariably the case, nothing much has to be done to rectify it. It simply means that the draft of the vessel is a few inches more, and a slight reduction of speed at the worst is entailed. This would be equally true of the submarine were it only intended to navigate on the surface, but the submarine must be navigated submerged and to that end the water-ballast tanks must be *completely* filled. If the boat then were over-weight, she would simply sink to the bottom as soon as the tanks were filled and navigation would be impossible. Calculation to such a hair's-breadth degree of exactitude is, of course, impossible, and to make up for discrepancies in manufacture, a margin of reserve weight is provided for in the calculations of about 3% of the total. In the course

of construction, however, alterations and discrepancies have in nine cases out of ten reduced this theoretical margin to a few hundred pounds, and there are numerous cases on record in which the ballast tanks have had to be reduced in size after the vessel was completed.

The system of tanks known as main ballast tanks constitutes the principal water ballast in the submarine and forms about 20% to 22% of the total reserve buoyancy of 25%.

The next tank in importance, variously known in different navies as the central tank, the midship tank, the buoyancy tank or the auxiliary tank, is situated in about the middle of the vessel's length and, in contradistinction to the main ballast tanks, this tank must *never* be completely filled when the vessel is submerged.

In a preceding paragraph it was mentioned that a submarine must be capable of submergence in sea-water of any degree of salinity. This statement will not make much of an impression until it is reduced to figures. Take the case of a submarine of 900 tons submerged displacement in fresh water. The salinity of pure sea-water is about 3% greater than fresh

water, so that the same vessel would displace 927 tons in salt water. As the main ballast tanks are already completely full, some place must be found for the 27 tons of additional water ballast that must be taken on board to bring the boat into "diving trim." Moreover, there are differences of weights from day to day due to variations in the supply of stores and in the number of men on board. For a vessel of this size, therefore, a central tank of more than 27 tons' capacity would be required, which would be practically full when navigating in salt water, and practically empty when navigating in fresh water. In practice it has been found possible somewhat to reduce the size of this tank because vessels that are designed to operate on the high seas practically never have the occasion to navigate submerged in fresh water; but, on the other hand, vessels stationed near the mouth of a large river find variations in the density of the water equal at least to 2% of their total displacement, which, in the case of a 900 ton vessel, would require a tank of more than 18 tons' capacity for that purpose alone.

The next tanks in importance are the forward and after trimming tanks. These tanks are sit-

uated as near the bow and stern, respectively, as convenient, and are utilised for producing slight changes in the longitudinal inclination when trimming for diving. There is no empirical rule to determine the size of these tanks which has usually been fixed by the judgment and experience of the designer. It has been found with different types and also with vessels of different size of the same type, that variations in the longitudinal inclination of the vessel when trimmed for diving affect the stability of equilibrium and affect the ease with which the vessel can be steered at a given depth under water; hence the trimming tanks are used to obtain the exact trim in each individual case which practical experience has shown to be most suitable.

All of the foregoing tanks are found in one form or another in all existing types of submarines.

We now come to another class of tanks called compensating tanks, under which heading are found fuel compensation tanks, fresh water compensation tanks, torpedo compensation tanks and lubricating oil compensation tanks. One of the great immutable laws in submerged

navigation is that there must be no change of weight and no appreciable change in the position of weight while the vessel is navigating submerged, and any material change of weight taking place during a long run on the surface must be compensated for before again submerging. For every torpedo fired, an equivalent amount of weight must be taken on board and in approximately the same longitudinal position as that occupied by the torpedo. Likewise, fuel oil and lubricating oil consumed by the engines in the surface run, and fresh water consumed by the crew, must be compensated for by their equivalent weight in sea water. The paramount advantage possessed by the storage battery over any other prime mover by which it is pre-eminently adapted for submerged navigation in spite of its many known disadvantages and deficiencies, is that during the process of discharge of its stored electrical energy there is absolutely no change in its weight.

The system of compensating tanks is likewise common to all types of submarines inasmuch as it involves one of the first principles. Various types of submarines have other special tanks for particular purposes, none of which may

be considered as essential, however. There is the adjusting or regulating tank, which by its comparatively small size is suited for containing and measuring small quantities of water. Such a tank has some use in accurately trimming for diving in a rough sea. It has been found, however, to be hardly worth the trouble of fitting it. Conditions of actual war have demonstrated the danger of delaying diving in an effort to obtain the most satisfactory trim. It has been found that the presence of an enemy destroyer coming straight at you at thirty-knot speed, with your periscopes already under fire, is an excellent inducement to quick submergence, and this operation is now performed in as many seconds as it took minutes during peace manœuvres, and the exactitude of trim which is desirable is obtained after the vessel is submerged. The man operating the diving gear can readily sense when this condition has been obtained. In some types it has also been the practice to install a so-called safety tank which is intended to be blown out by air at considerable depth in case of an accident submerged. This arrangement has been rendered obsolete by the more modern practice of making all the tanks safety

tanks. In other words, all the tanks are or should be capable of being blown out in order to bring the vessel quickly to the surface in case of accident at the maximum depth of submergence that the ship's structure can withstand.

### STABILITY

It is difficult to deal with this question without having recourse to technical terms, for the measure of stability is what is known as the metacentric height. If one may compare the action of a vessel rolling transversely in a seaway, with that of a pendulum suspended from a fixed point, the "metacentre" may be said to represent the fixed point about which the vessel rolls. The "metacentric height" is the distance between the metacentre and the centre of gravity, the centre of gravity being the common centre of all the weights that go to make up the ship's structure. Without going into a lengthy explanation which would necessarily be of a technical nature, it will suffice to state here that the metacentric height of a double hull submarine is inherently greater on the surface and less submerged than for a single hull submarine. In a double hull submarine the meta-

centric height varies from 18 to 30 inches on the surface and from 8 to 9 inches submerged. The metacentric height of a single hull submarine on the other hand, varies from 8 to 12 inches on the surface and from 10 to 15 inches submerged. These figures, as such, will not mean very much, nor is it to be assumed that the greater the metacentric height, the better. Excessive metacentric height is just as detrimental as insufficient metacentric height. The double hull vessel having a greater metacentric height on the surface has a short rolling period and adapts itself to every change in the wave surface. It is likely, therefore, to be more uncomfortable in its movements than the single hull vessel which has a longer rolling period and in a heavy sea rolls considerably less than the double hull vessel, substituting therefor a curious lateral motion which seems as if the vessel were shifting bodily from side to side. In submerged navigation, although there is a difference in the metacentric height between the two types, it is not sufficient to materially affect conditions of navigation.

# CHAPTER III

## Elements of Design—Power Plant

### MOTIVE POWER—SURFACE

The power plant for propelling all existing submarines is on the dual system, i. e., there is one method for propelling the vessel on the surface, and an entirely different and separate method for propelling the vessel submerged. The necessity for a dual system lies in the fact that no satisfactory prime mover adaptable to both conditions has yet been devised, although therein lies the obvious course for the future improvement and development of the submarine and much experimentation in this line has already been conducted, but so far without results sufficiently promising to be considered a satisfactory solution.

In the earlier submarines, an ordinary steam engine and boiler plant supplied the motive power for surface propulsion. This was found in practice to be very unsatisfactory because

the firing of boilers with fuel oil had not yet been perfected and coal fired boilers on board a submarine could only be handled with difficulty. Moreover, the engine was inefficient and it was found almost impossible to dissipate the heat generated in the boiler, with the result that the atmosphere in the boat when closed up for a submerged run became stifling and unbearable.

About the year 1885 the gasoline engine was generally introduced in place of the steam engine and boiler plant, thereby marking a long step forward in the development of the submarine. Not alone was the cumbersome boiler with its large funnel dispensed with, but gasoline as a liquid fuel could be stowed in spaces that could hardly be used for any other purpose, and the greater efficiency and reduced fuel consumption of the gasoline engine immediately made a considerable improvement in radius of action possible.

The gasoline engine generally used operated on the same principle as an ordinary automobile engine, except that it was, of course, of much heavier construction and run at a much lower speed. The power of the engine was

transmitted to the main shaft through the medium of a friction clutch in precisely the same way as the power of an automobile engine is transmitted to the shaft that drives the rear wheels. This type of prime mover was universally employed until about 1910, when it was superseded by the so-called Diesel engine. This engine was named after the inventor and holder of the basic patents, Dr. Rudolf Diesel of Munich. The Diesel engine had long been in existence as a stationary engine for supplying power for factories and for similar industrial purposes, but the type employed for that purpose was very heavy in construction and slow in speed, entirely unsuited to the stringent requirements for submarines. For the latter purpose an engine of high rotative speed and comparatively light in weight which would develop the maximum power in the minimum space, was requisite, and it was in the transformation of the Diesel engine from the slow-speed factory type to the high-speed marine type that the numerous engineering difficulties were encountered which rendered its adoption for submarine purposes impossible before 1910. The Diesel engine as a slow-speed motive

power for factories is exceedingly reliable, but as soon as an attempt is made to make it conform with marine, and especially submarine, requirements, the stresses in the material are so enormously increased that the reliability rapidly diminishes. It was just this difficulty that militated against the Diesel engine in 1910 as an ideal motive-power for submarines, and the same difficulties inherent in the type of the engine are present, although to a lesser degree, to-day. On the other hand, it has manifest advantages as compared with the gasoline engine, the most important of which is the fact that its consumption of fuel per horse-power is only about half as much as that of the gasoline engine. Consequently, with engines of the same power in a boat with a given fuel capacity, the radius of action is nearly doubled. There is also the advantage that it utilizes crude oil, which is relatively more easily obtainable and cheaper than gasoline, not to mention safer. Gasoline, as every one knows, is a very volatile liquid and in spite of great precaution, it is almost impossible to prevent leakages of small quantities into the boat. In a confined space with the ever present possibility of a spark be-

ing produced in some part of the electrical equipment of the boat, the danger of explosion was serious; in fact, before the general adoption of Diesel engines there were several cases on record of fatal accidents due to gasoline explosions, although from a purely military point of view the greatly increased radius of action afforded by the Diesel engine should be the primary consideration in adopting machinery of that type.

It is unquestionably a fact that the introduction of the Diesel engine was forced by the pressure of public opinion consequent upon the several fatal accidents and explosions that were attributable to the presence of gasoline on board.

Every one who has ever run a motor car is familiar with the system of operation of the engine, which is almost invariably of the four cycle type. The expression "four cycle" simply means that four strokes of the piston take place for every explosion, two down strokes and two up strokes. On the first down stroke, the explosive charge, consisting of a mixture of gasoline and air, is drawn into the cylinder. On the first up stroke, it is compressed. At the end

## POWER PLANT

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U. S. SUBMA...

of the compression stroke, the charge is exploded by the action of the spark plug, and the second down stroke, during which the expansion of the exploded gases takes place, imparts the power to the shaft. The second up stroke, which is the fourth and last of the cycle of four strokes, expels the exploded gases, and the next down stroke, during which a new explosive charge is drawn in, again commences the cycle of four strokes.

The cycle of operations in a four cycle Diesel engine is analogous to that of a four cycle gasoline engine, except that the sparking device is dispensed with and the explosive charge is fired by the heat due to its own compression. In the first down stroke of a Diesel engine, the cylinder draws in fresh air only. No fuel oil may be admitted on the down stroke because the degree of compression required to fire the charge in a Diesel engine, depending as it does upon the heat generated by compression, is much greater than in the gasoline engine and there would be a danger of the charge being prematurely fired.

The first up stroke of the cycle is utilised for the compression of the fresh air that has been drawn in on the first down stroke to a pressure

of about 500 lbs. per square inch. The temperature of the air due to this compression is about 1,000° Fahr. At the end of the compression stroke, at a point corresponding to the one in which the spark occurs in the gasoline engine to fire the explosive charge, a jet of fuel oil is injected under air pressure of about 1,000 lbs. per square inch into the highly compressed and intensely heated volume of air in the cylinder, and immediately produces combustion. The second down stroke, as in the case of the gasoline engine, is caused by the expansion of the ignited charge and imparts power to the shaft. The second up stroke, which is also the fourth and last stroke in the cycle, is utilised, as in the case of the gasoline engine, for exhausting the burnt gases, after which the cycle re-commences.

In many submarine Diesel engines now in service the so-called two cycle engine is employed. This is an engine in which there is one explosion for every two strokes of the piston instead of for four strokes. In the two cycle engine, the in-take of the charge of fresh air practically synchronises with the exhaust of the burnt gases. In engines of this type the greater part of the burnt gases escapes through

exhaust openings at the bottom of the cylinder, which are uncovered by the piston when it reaches its lowest point. It is also customary to fit low-pressure air pumps which supply scavenging air to the cylinders. The scavenging air is admitted through valves in the cylinder head and its admission materially assists in clearing out the burnt gases through the exhaust openings at the bottom of the cylinder. The valve gear of the two cycle engine is much simpler than that of the four cycle, but the two cycle necessitates the additional complication of a low-pressure air compressor, as mentioned above, and the economy in fuel consumption is much lower than in the four cycle engine.

Whereas the high speed, light weight Diesel engine has been developed to such a point of reliability that its adoption for smaller submarines is quite practicable, the rapid development in size of the submarine has rather outdistanced the progress that has been made with the Diesel engine. In the construction of marine Diesel engines of a size in excess of 150 to 200 h.p. per cylinder, serious engineering difficulties have developed due to the necessity of thickening the walls of the cylinder. In the

smaller sizes, with comparatively thin cylinder walls, the conductivity of the metal is such that the heat generated in the cylinder can readily be dissipated by the circulation of water in the water jacket surrounding the cylinder. In the larger sizes, however, in which the cylinder wall necessarily becomes thicker, the intense heat inside the cylinder, coupled with the low temperature of the outside of the cylinder wall due to the cooling water, produces excessive strains in the metal itself, resulting in cracked cylinders and pistons and also cracked cylinder heads.

It is just this difficulty that has caused those interested in the development of the submarine to cast around for some other form of prime mover that will obviate the difficulties mentioned. With that end in view, and taking into consideration the great advance that has taken place in engineering generally in the meantime, steam is again being considered and employed as a prime mover. In the latest boats in which this system has been adopted, the boilers are fired with oil fuel and for the old-fashioned steam engine has been substituted gear turbines. While a much higher degree of efficiency

has been obtained than was possible twenty years ago and satisfactory means have been found for insulating boilers, the sacrifice of a large part of the steaming radius on the surface has nevertheless been entailed, and it is very doubtful if the steam plant will permanently displace the Diesel engine as soon as the latter is further developed in the larger sizes. This is still more likely to be the case in view of the fact that the Diesel engine lends itself more readily to the efforts that are being made to devise a single system of propulsion whereby the storage battery and electric motor for submerged propulsion may be dispensed with and the military efficiency of the boat greatly enhanced.

At the present time it is impossible to use either a gasoline engine or a Diesel engine submerged because of the enormous quantity of air required for their operation. Here again, every one familiar with the automobile engine will realise that a large amount of air is necessary, but unless one has taken the trouble to calculate it, it will hardly be credited that the entire quantity of free air in the submarine would be consumed by the engines in a compara-

tively few seconds and as the boat is hermetically sealed when submerged, there is no means of replenishing the air supply. The uselessness of the Diesel engine for submerged propulsion must be at once apparent. Even if every corner of available space, every pound of available weight, were taken up with highly compressed air in steel flasks, the supply of air would not be sufficient to propel the boat submerged for one-third of the time that is now possible with storage batteries. Many experiments have been conducted on engines operating on the so-called closed cycle, in which the exhaust gases are drawn into the cylinder and used over and over again, each time being mixed with the necessary quantity of oxygen to again produce a combustible or an explosive mixture, but so far these experiments have led to no reliable practical result. When that problem is solved, that is only the first of many problems which arise in connection with the use of Diesel engines submerged. There is the problem of automatically compensating while running submerged for the loss in weight due to the consumption of fuel oil, which does not arise where the storage battery supplies the motive power

inasmuch as there is no change in the weight of the battery during the process of discharging. All these difficulties are, however, minor engineering problems which will undoubtedly be solved before the main problem of operating on the closed cycle has found a satisfactory solution.

In an effort to dispense with the storage battery, M. d'Equevilley has been conducting experiments in conjunction with the Weser Werft in Germany, in which a chemical boiler supplying steam to a steam turbine has been employed. Steam is generated in the ordinary way for surface propulsion, and for submerged propulsion the steam engine is employed in connection with a soda boiler in which steam is generated by a process of slaking caustic soda. The process can be continued until the saturation of the caustic soda necessitates the vessel returning to the surface, after which the soda must be reconcentrated before submergence again becomes possible. This system had not developed further than the experimental stage upon the outbreak of the war and, as far as it has been possible to ascertain, nothing further has been done with it since the war broke out. An Ital-

ian engineer named del Prosposto has also evolved a scheme for the submerged propulsion of submarines by means of the Diesel engine. The engine was used in the ordinary way for propelling the boat on the surface and at the same time drove an air compressor by which air under high pressure was stored up in steel flasks, the intention being that this same air would be utilised in running the engine submerged. An experimental boat incorporating this system was built some time ago in Russia but probably for the reasons just set forth nothing practical was ever completed.

### MOTIVE POWER SUBMERGED

In view of the fact that it has not yet been found practicable to utilise either the Diesel engine or the steam engine for propulsion submerged, it has been necessary to resort to the electric storage battery operating in conjunction with electric motors to supply the energy for propelling the vessel submerged. While the storage battery labours under many disadvantages and has certain defects which must be considered inherent, it has nevertheless the very considerable advantage that has been hereto-

fore mentioned, viz., the fact that the weight of the battery is not susceptible to change during the period of discharge. Moreover, electric power for submerged propulsion is practically noiseless. This is a very important factor, for with the extremely sensitive sound-detecting devices that are now in use, the location of an enemy submarine would be a comparatively simple matter if propulsion were effected by any medium that was not noiseless. It is, of course, a fact that the propeller itself produces a considerable volume of sound which can be heard at some distance with the sound-detecting device, but all vessels are supplied with propellers, so that this particular noise would not necessarily indicate the presence of a submarine. As matters now stand, if the operator listening at the instrument for the approach of an enemy submarine hears the sound caused by a revolving propeller and notifies his commanding officer, only two alternatives are possible: either a vessel must be in sight or a submarine must be in the neighbourhood. This deduction is based, of course, on the assumption that it is daylight. While it is true, therefore, that the presence of a submarine can be detected at a

certain distance by a sound-detecting device, the substitution of Diesel engine propulsion submerged, if it became feasible from the engineering point of view, would undoubtedly increase the range at which the approach of a submarine could be heard and would militate to just that extent against the probability of approaching within torpedo range.

The ordinary storage or accumulator battery, technically known as the secondary battery, is often discussed without a very clear conception of just what it is. Those of us who have not forgotten the chemistry we once learned, will recall that a primary battery, in contradistinction to a secondary battery, is one in which the two elements, one of which must be an electropositive substance and the other an electro-negative substance, are immersed in an electrolyte, and a flow of electric current takes place as soon as the terminals are brought together and continues for a certain length of time until a chemical equilibrium has been established between the two elements, which is technically called polarisation. When this point has been reached, no more current will flow until the electrolyte is renewed.

It will be quite obvious that the use of a primary battery for submarines in which the renewal of an enormous quantity of electrolyte would be necessary at the end of every discharge, is perfectly impossible. It is necessary, therefore, to have recourse to a secondary or storage battery in which the electrolyte does not have to be renewed, but which, on the other hand, must be charged with electricity before it can be discharged. As it is technically feasible to re-charge the storage batteries on a submarine, this particular characteristic offers no serious objection, except that the submarine cannot submerge while the batteries are being charged. To re-charge the batteries, the electric motors that are used for propulsion submerged are driven by the Diesel engines, in this way serving as electric generators to re-charge the batteries. In view of the fact that the Diesel engines are required for this purpose and the Diesel engines cannot be operated with the boat submerged, it follows that to re-charge the batteries the boat must be on the surface.

The Diesel engine, the electric motor and the propeller are all on one continuous line of shaft with couplings between them so that the pro-

peller may be driven either by the engine or by the motor. By the manipulation of these couplings it is possible to charge the batteries when the boat is lying in the harbour by uncoupling the propeller, or the batteries may be charged while the boat is navigating on the surface with the Diesel engines by permitting the propeller coupling to remain engaged.

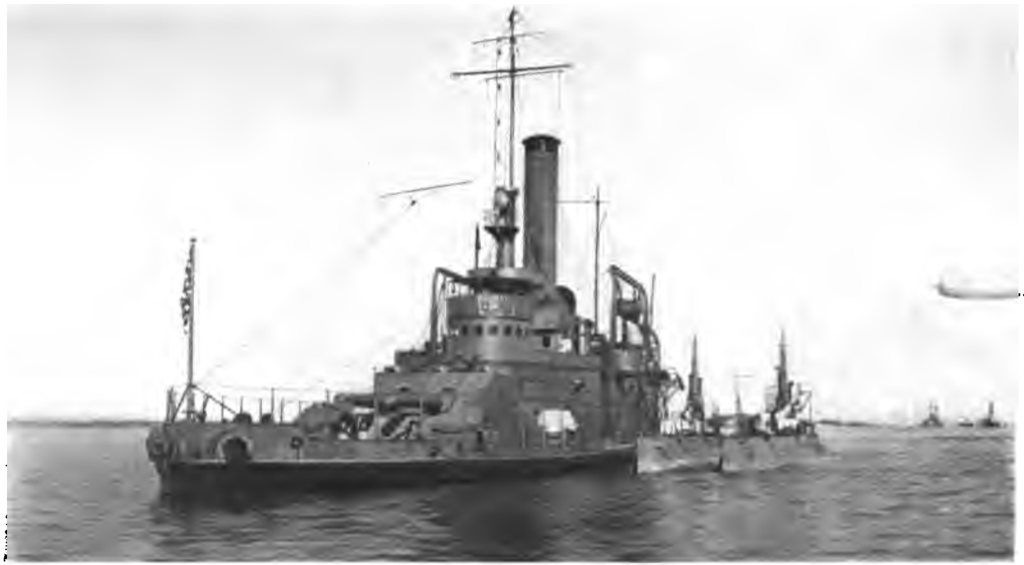
While there are several types of storage batteries and several variations of each type, what is called the lead cell is the only one that has been extensively employed. Each cell consists of a group of positive and negative plates immersed in an electrolyte of dilute sulphuric acid of a density of about 1,215 as compared with fresh water, which is 1. This particular strength of electrolyte has been found most suitable in practice as strengthening or weakening of the electrolyte not only has a detrimental effect upon the plates, but also increases the resistance to the flow of electric current through the electrolyte from the positive plates to the negative plates. The positives and negatives in each cell alternate, and the total number of plates per cell varies from about 20 to 45. The active material of the positive plates is lead

peroxide, and spongy lead for the negative plates.

The batteries of earlier submarines were usually equipped with positives and negatives formed by the Planté process, named after the inventor. The Planté plate is one in which an intricate lead grid is cast and the material reduced to peroxide of lead for the positives, and spongy lead for the negatives, by an electrochemical process. In later boats the Planté plates have been superseded by pasted plates in which the active material consists of a pasty composition of lead and antimony compressed into a grid cast to receive it. The plates are subjected to the same process as in the case of Planté plates, which reduces the positives to peroxide of lead and the negatives to spongy lead, but the capacity of a battery composed of pasted plates, for the same weight and space, is nearly 30% greater. This increased capacity, however, is only possible with the sacrifice of a certain amount of the life of the battery. A battery of pasted plates should have a life of about 300 complete discharges, and a battery of Planté plates a life of 500 to 600 complete discharges. These figures for the life of a battery

are, however, very approximate, for it is much more erratic and variable than the life of a motor car tire. Some pasted plate batteries now in service have already completed 500 discharges and are still doing good work, and others, with all possible care, will be worn out after 200 discharges. It must be borne in mind that careful treatment is of extreme importance, for at any stage in its life a battery can be completely ruined in a day by inexpert handling.

Another type of battery of which one has heard much is the Edison battery. This has been fitted experimentally in one American submarine but has not as yet been introduced in Europe. The Edison battery is of much more substantial construction and materials than the lead battery, the positive plates consisting of nickel hydrates in a steel frame, and the negative plates consisting of two perforated steel plates, containing between them a quantity of iron oxide which forms the active material. The electrolyte of the Edison battery is an alkaline instead of an acid solution, being made of caustic soda. The Edison battery has a longer life and will stand much more careless handling than the lead battery, but its inherent disad-



U. S. S. Tallahasee, U. S. Submarines K-6 and K-5, Hampton Roads

vantages, apart from the fact that it is more than double the price of a lead battery, seem to outweigh any advantages it possesses. The Edison battery may be allowed to stand an indefinite length of time after being discharged before re-charging, without suffering much deterioration, which is not the case with a lead battery. There is less liability of corrosion to the steel structure of the boat from the alkaline electrolyte than there is from the acid, and the accidental entrance of sea-water into the cells will not produce the suffocating fumes of chlorine gas, as in the case of the lead battery. On the other hand, the Edison battery generates hydrogen gas in large quantities, both when charging and discharging, with the ever present danger of explosion in case a spark should find its way into the ventilating ducts, and likewise it generates heat during both the charging and the discharging processes. As there is a point at which the charging process must be stopped if the temperature becomes too high because of the deterioration resulting in the plates, this tendency to heating could prove a troublesome factor to deal with if a boat were so situated

that frequent discharging and re-charging of the battery were necessary.

It has been claimed for the Edison battery that it is much lighter than a lead battery of the same capacity. This is indeed a fact, but it is not a fact which can be turned to much advantage by the submarine constructor, inasmuch as the space occupied per unit of electrical capacity is practically the same as for a lead battery. The lightness of the battery could be made use of if it were possible to find more space in which to put additional cells, but as the limitation of space in any given design determines the power of the battery, this particular feature of the Edison battery avails nothing. In fact, in the case of a submarine, the constructor depends to a great extent upon the weight of the battery for the stability of the boat, so that a great economy in weight in the battery would so largely reduce the stability that the deficiency would probably have to be made up by putting ballast in the keel.

Then again the efficiency of the Edison battery is lower than that of the lead battery. The efficiency in this sense simply means the amount of power you get out of the battery compared to

the amount that has previously been put in. Until the battery is charged you do not get any power out of it at all. In a lead battery which has been charged with 100 units of power, the limit of discharge will have been reached when 85 of these units have been given out in the form of power, i. e., the efficiency of the battery is 85%. You get out 85% of the amount of current put in, and 15% is lost. In an Edison battery of the same type, the efficiency would only be about 70% so that 30% is lost. The expression "unit of power" used here bears no relation to any particular standard electrical unit of measurement, but is only used to show the relation between the amount of power required to charge the battery and the amount of power delivered on discharge.

The question has often been asked, "How does one know when the battery is fully charged, and how does one know when the battery is fully discharged?" While this can be determined in several ways, the easiest method is by the voltage. When the battery is fully charged, each cell has a voltage of about two volts, so that a battery of 60 cells would show a reading of 120 volts on the volt meter. The-

oretically, the battery can be discharged until the voltage is zero, and if not stopped will, in fact, discharge itself to that point, but that would involve the total destruction of the battery. In practice it is found desirable to stop the discharge when the voltage has dropped to 1.7 volts per cell, or 102 volts for a battery of 60 cells. It might appear from these figures that a large part of the potential capacity of the battery was not drawn upon, but in point of fact the voltage drops with such tremendous rapidity after 1.7 volts per cell has been reached that it would only be a question of a few minutes before the voltage was down to zero.

Another very accurate indication of when the battery is fully charged or discharged is furnished by the meter, which indicates exactly how much current has passed into the battery or out of it, as the case may be.

The control of the electric motors which propel the boat submerged is effected generally from the central station by means of what is known as a contactor gear. The switches for controlling the electric current are not operated by hand, but are operated electrically by push-buttons in the central station under the eye of

the commanding officer, and the operation has been reduced to such a degree of simplicity that it may well be compared with running a pianola. Interlocking arrangements are provided in the control gear to prevent the possibility of making any mistakes in operation. It has been brought to such a degree of perfection to reduce the element of error and to eliminate the personal equation as far as possible, that the only switch that one *can* operate is the one that should be operated. An inadvertent attempt to operate the switch gear improperly would only result in nothing happening.

# CHAPTER IV

## Elements of Design, Equipment

### MISCELLANEOUS MACHINERY

*Steering Gear.* Steering stations are fitted on the navigating bridge on top of the conning tower, in the conning tower and in the central station. In very small vessels up to 200 tons, displacement, a hand steering gear is found sufficient, but for vessels of greater size an electrical steering gear is necessary, the power for operating which is obtained from the storage battery. In addition to the electrical gear a hand gear is usually fitted to be used in case of breakdown in the electrical gear.

Each steering station is provided with a mechanical indicator showing the position of the rudder, and with a repeating compass if a gyroscopic master compass is fitted. In case magnetic compasses are used, each steering station is provided either with its own compass or an image reflected from the master compass.

*Diving Gear.* The type of gear for operating the diving rudders or hydroplanes is substantially the same as for the steering gear. In vessels provided with diving rudders at the bow and stern, or with two pairs of hydroplanes, the forward and after rudders are usually operated by two separate hand wheels in the central station under control of two men who receive their orders from the first officer. Each of the two operators is provided with a sensitive depth gauge not less than 12 inches in diameter which indicates the exact depth of the vessel below the surface. In addition to the depth gauge, each operator is supplied with an indicator showing the exact position of the rudder under his control, and another indicator showing the inclination of the boat. By continuous observation of the two indicators and the depth gauge, it is possible to steer a course submerged in smooth water that will not vary more than 12 inches above or below the pre-determined depth. It is customary, also, to provide the diving rudder operators with indicators showing the position of the steering rudder, as the boat when turning submerged always has a tendency to come to the surface, which can far better be counter-

acted if the diving rudder operator can follow the movement of the steering rudder and anticipate any change in the trim or depth of the boat.

*Statical Diving Gear.* Ordinarily speaking, it is impossible for a submarine to remain submerged unless she is under way at a speed of at least four knots. This represents the consumption of considerable electrical energy, and in circumstances where it is desired to remain in the same position without coming to the surface, it is very inefficient and uneconomical to be obliged continuously to consume the amount of energy that is necessitated by a speed of four knots. To obviate this, a device commonly known as the statical diving gear is fitted, which accomplishes the same purpose with a much smaller consumption of electrical energy. Various types of this mechanism are employed, but in principle they are all alike. With the boat in diving trim, a certain amount of water is admitted very slowly into the central ballast tank until nothing but the tops of the periscopes remain above water and the apparatus maintains this state of equilibrium. Any tendency of the boat to sink too deep is checked by the

discharge of a small quantity of water, and any tendency in the contrary direction is counteracted by the admission of water. With the consumption of energy of not more than 1 to 2 h.p., it is possible for the vessel to remain for hours in this position, observing the entire horizon but remaining herself immune from observation or attack.

*Air System.* A number of seamless steel air-flasks are installed, containing compressed air at a pressure of 2,500 lbs. per square inch. This air, after passing through suitable reducing valves to reduce the pressure, is utilised for blowing the water out of the tanks, charging the air vessels of the torpedoes, charging the flasks for firing the torpedoes, blowing the whistle and refreshing the air in the boat when submerged for long periods. Separate flasks containing air at a pressure of 1,000 lbs. per square inch are generally fitted to start the main Diesel engines. One or two high-pressure compressors are installed of sufficient capacity to charge all the flasks up to their full pressure in about four hours. As explained in the section relating to safety devices, the valves controlling the supply of air to the various tanks are gen-

erally grouped in not less than three compartments.

*Water Piping System.* Two or three electrically driven main pumps and one or two auxiliary pumps are generally installed in connection with a complete duplicate system of water piping to every tank in the boat. The pumps are distributed in various compartments so that by no conceivable chance can any accident incapacitate all the pumps. Moreover, the control valves connecting the pumps to the various tanks, as in the case of the air valves, are grouped in not less than three compartments for the same reason.

*Refrigerating System.* The refrigerating system is only installed in boats that are intended for tropical service, but its uses are manifold. Its primary function is to cool the battery when the battery is being charged, as it is very detrimental to the life of the plates to permit undue heating. In addition to cooling the battery, it is also used for distributing cool air through the living quarters and through the lockers in which perishable food is stowed.

*Heating System.* A heating system is usually fitted only upon boats intended for service in

cold climates, although formerly they were not so arranged and any one who has made a trip in mid-winter in the North Sea or North Atlantic under these conditions will surely appreciate the desirability of some satisfactory method of heating. Electric heaters have been tried but have been abandoned owing to their excessive consumption of electrical energy. In later boats ordinary steam heaters operating in conjunction with an oil-fired boiler are being installed. When the Diesel engines are running, the heat from the exhaust pipes is utilised to supplement the steam heaters.

*Anchor Gear.* An efficient anchor arrangement is something which until recently has been quite neglected. Many of the earlier American boats were only fitted with a primitive mushroom anchor which could be raised or lowered from inside the boat, but which could not be depended upon to hold fast under conditions when it was most necessary. In other navies an anchor of the regulation type was fitted, but it could not be lowered without sending some members of the crew on deck to open up the superstructure hatches under which it was concealed, and clear it. It frequently happened

that just when the weather was so rough that anchoring became necessary, the same weather conditions made it impossible to send any men on deck to clear the anchor. This has now been improved and all later boats of the larger type are fitted with two bow anchors, either one of which is capable of holding the boat, and both of which can be operated from inside the vessel. This latter qualification is important as it is frequently desirable to anchor submerged. An arrangement is made to cut the cable, where a steel rope is used, or to slip the chain, where a chain is employed, to guard against the possibility of anchoring submerged and not being able to get free again.

*Navigating Appliances.* In addition to the periscopes, which are essentially for the purpose of submerged navigation, all vessels of the latest type are now provided with a gyroscopic compass set. This consists of a master compass, usually located in the central station, and three repeating compasses which are operated magnetically from the master compass and are located at the three different steering stations. The recent improvements in the gyroscopic compass that have made it practical for use on

submarines, have been of inestimable value, especially in submerged navigation, as the magnetic compasses which were formerly employed were subject to most erratic and serious deviation for which no proper compensation could be effected, due to the heavy and variable electrical currents flowing in the battery. The impossibility of locating the magnetic compass at any distance from the steel hull, coupled with the presence of a variable number of steel torpedoes on board from time to time and in different positions, only added to the difficulties inseparable from the use of the magnetic compass.

A sounding device to permit the depth of water to be accurately measured, both when running on the surface and submerged, is a necessary adjunct to the navigating appliances of a submarine, especially when the vessel is intended to be used in waters that have not been very completely charted.

The other navigating appliances, such as engine-room telegraph, voice pipes, navigating lights, etc., are, of course, fitted, but as they are in no way peculiar to a submarine and are such as may be found on any ship, no particular description of them will be required here.

*Air Regenerating System.* An air regenerating system has hitherto only been fitted to any extent in submarines of the German Navy and in those of the same type built by Germany for the Austrian Government. In other navies it has been generally considered that the fresh air in the boat along with the compressed air in the storage flasks was quite sufficient for the purpose, without the additional complication of an air regenerating system. This standpoint is based on the assumption that it will certainly be possible for a submarine under any conditions to come to the surface unobserved at least once in every twenty-four hours and replenish the supply of fresh air in the vessel. As that is sufficient to support the entire crew for a period of more than twenty-four hours, the particular advantage of the additional complication of a regenerating system to enable the vessel to remain submerged for seventy-two consecutive hours is not quite apparent.

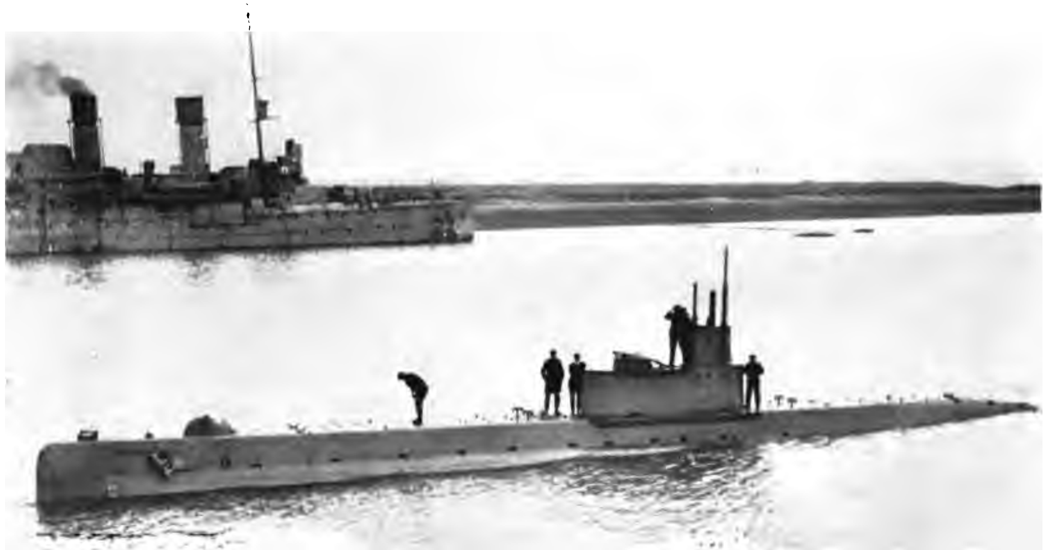
The air regenerating system is merely an extension of the same principle as the safety helmet. Every compartment in the boat is provided with a vessel containing a chemical compound which absorbs the carbon dioxide in the

air and several steel flasks charged with compressed oxygen in the same compartment automatically replace the oxygen that has been consumed in breathing. On every occasion when the vessel returns to its base, the empty flasks of oxygen have to be replaced with charged flasks and the chemical saturated with carbon dioxide has to be renewed.

### EXTERNAL FITTINGS

In vessels of the double hull type, as well as the single hull, with the exception of the Laurenti type, it is customary to fit a superstructure or walking platform, built up of light plating, for practically the entire length of the vessel. It also serves to cover a quantity of gear on the upper side of the boat, that would otherwise offer considerable resistance to propulsion, such as anchor gear, entrance and escape hatches, lifting eyes, engine exhaust pipes, etc. Other portions of the superstructure are utilised for lockers for the stowage of ropes, hawsers and cork fenders. The conning tower is situated about amidships. In earlier designs, the conning tower was hardly more than a mere protuberance above the hull. As

the conning tower must be used for navigating the boat on the surface, when the weather is so rough that navigation from the navigating bridge is impossible, it was soon demonstrated that a conning tower of some considerable height was necessary. In some of the German boats the conning tower has a height of 9 feet above the superstructure deck. At the same time that the height was increased the diameter was likewise made greater and is usually not less than 36 inches at the bottom, tapering to 30 inches at the top in submarines in which neither of the periscopes enters the conning tower. In submarines like the German boats, where one of the periscopes enters the conning tower, in which the tower virtually becomes the central station during submerged navigation, the tower must necessarily be made much larger to accommodate two or three men and to give the commanding officers sufficient room to walk around the periscope. In such vessels, the conning tower may have the width of 4 or 5 feet and a length of 6 to 8 feet, the cross section being elliptical. To reduce the resistance of the conning tower in submerged propulsion a light non-water tight wave breaker or fair-



Dutch Submarine 07 in Surface Trim

water is fitted which serves at the same time as a housing for ventilators and periscopes, the upper part of which is made flat and serves as a bridge when navigating on the surface. The top of the conning tower projects just enough above the top of the fair-water to accommodate the sighting ports in the conning tower. The sighting ports, about 8 in number, are fitted with plate glass from ¾ inch to one inch in thickness to resist the pressure due to deep submergence, and in addition bronze safety covers are arranged to be screwed quickly in place in the event of the glass breaking. The railing that one usually sees in photographs around the superstructure deck and the navigating bridge is portable and is removed when the vessel submerges. In fact, its only use is in time of peace. On active service it is not in evidence at all.

Externally a submarine does not look like a very complicated piece of mechanism. There are a few devices on the outside of the boat, however, the use of which may not readily be understood. At the bow will invariably be found a towing-hook to which a tow rope may be attached in case the submarine is disabled.

Somewhat abaft the bow the forward diving rudders will be observed, either in the extended or in the folded position. Where diving rudders are fitted above the normal surface water line, it has been found necessary to make arrangements for either folding them up against the side of the superstructure or withdrawing them entirely inside the superstructure. Otherwise a blow from a heavy sea would be likely to put them out of commission. They are only extended when the vessel is making a submerged run, and folded up again when the vessel comes to the surface. This operation must be effected from inside the boat as in heavy weather it would be impossible to do it otherwise.

Another object which may strike the eye in looking over the deck is what appears to be an inverted bell. This is the submarine bell for transmitting signals under water and its exposed position, entirely free of the structure, is due to the fact that it will only operate satisfactorily in a position where no part of the ship structure can impede the sound waves. The large vertical pipes that may be seen projecting from the wave breaker are the ventilat-

ing pipes for supplying fresh air to the living quarters and to the engines and for leading off the exhaust gases from the battery. Where the two periscopes are not too far apart, it has sometimes been found convenient to put a fair-water around them which extends for some considerable distance above the fair-water around the conning tower. On large submarines it is now customary to install a folding boat that can be stowed in some convenient part of the superstructure.

### LIVING ARRANGEMENTS

Living arrangements in recent boats have undergone a radical improvement as compared with what would have been found ten years ago. This is, of course, due partly to the increase in the size of the boats themselves. A boat of 800 tons, carrying a crew of 3 officers and 20 men will be provided with 3 separate cabins for the officers and fixed or folding bunks for the men. The officers' cabins will be fitted up in much the same way as officers' cabins on an ordinary ship, and the men will be provided with ample locker accommodation for their clothes and effects. The living quarters are

properly heated with steam in cold weather and the steel work is sheathed with compressed cork to absorb moisture.

The galley arrangements have also been materially improved. Cooking can most conveniently be done electrically, for which purpose a large and efficient electric range with 4 heating plates, an oven and a hot water reservoir is provided. Electric urns for holding coffee and soup are supplied and finally a regular cook is attached to the boat with no other duty than to attend to the cuisine.

## CHAPTER V

### ARMAMENT

#### TORPEDO TUBES AND GUNS

THE main armament of all submarines consists of a certain number of torpedo tubes, varying with the displacement of the boat. Although a certain number of the very latest boats are fitted with torpedo tubes for firing 21-inch torpedoes which have a length of about 21 feet, the great majority of submarines in service are equipped with tubes for firing 18-inch torpedoes with a length of about 17 feet. Small submarines of from 150 to 300 tons' displacement can accommodate two of these tubes fitted in the bow, and in larger vessels of 500 to 800 tons' displacement, the armament would consist of four to six tubes.

Submarines in the U. S. Navy of the coast-defence type having a displacement of 550 tons are practically all fitted with four torpedo tubes, all located in the bow. This is a practice that

has not met with favour in European navies as it is considered that a shot fired from the bow tube at close range gives the submarine a very short interval of time and a very small space in which to swing around and clear the enemy ship at which she has fired, and the larger the submarine the more serious does this consideration become.

In European navies, vessels of sufficient size to accommodate four torpedo tubes usually have two placed in the bow and two in the stern, and vessels carrying six tubes are fitted with two in the bow, two in the stern and two in the superstructure, the latter being either of the fixed or revolving type.

Militarily speaking, the revolving broadside tube has a very great advantage over the bow and stern tubes. As it is capable of being trained either to port or starboard through an arc of about 100° on each side, the zone of fire is much greater than with a fixed tube built into the ship's structure, and the broadside tube enables the submarine to take up a much more favourable position relative to the enemy ship that is being attacked. It has the serious disadvantage, however, that all of the adjustments

on the torpedo preparatory to firing must be made before the vessel submerges, and during submergence the launching tube and the torpedo are quite inaccessible.

In order to obviate these difficulties, a number of submarines in the British Navy have been built with two fixed broadside tubes in the interior of the boat: one firing to port, and the other to starboard. Inasmuch as these tubes are built into the structure of the vessel in the same way as the bow and stern tubes, it is impossible to train them on a target except by manœuvring the entire ship, whereby the zone of fire is materially reduced, besides which it is impossible to fire two torpedoes on one broadside. Moreover, the position which must necessarily be assigned to these tubes in the centre of the living space, constitutes an inconvenient obstruction. In its favour, however, it must be said that the internal tube not only permits the final adjustments on the torpedo to be made immediately prior to firing, but at the same time makes it possible to reload the tubes while submerged, which is the principal disability of the external broadside tube. A number of German submarines are fitted with fixed tubes in

the superstructure, built in at various angles. The fixed type, while necessarily sacrificing a large portion of the zone of fire as compared with the revolving type, is a much simpler and lighter piece of mechanism, consequently the weight available for armament will permit a larger number of fixed tubes to be installed.

The total number of torpedoes carried by a submarine is usually equal to twice the number of tubes, each tube being supplied with one torpedo and one reserve, although it is undoubtedly a fact that in larger boats under war conditions, the number of reserve torpedoes is materially increased by filling up every portion of available space at the expense of convenience and habitability. It would be quite possible for the 900-ton German submarines to carry as many as eighteen torpedoes under these conditions.

The question, "How is the torpedo fired submerged, and how can the tube be reloaded," has so often been asked that this point must be dealt with in some detail.

Consider the case of the internal bow tube. The principle is the same for any of the tubes,

but the mechanism for broadside tubes is somewhat more complicated.

The fixed bow tube is fitted at its outer end with a water-tight cap which can be opened or closed at will by a suitable mechanism inside the boat. Likewise the inside cover or breach can also be opened or closed by hand. When the tube is to be loaded, the outside cover is closed, the inside cover opened and the torpedo is pushed into place from behind in the same way as a cartridge would be loaded into a gun, except that the torpedo occupies practically the entire length of the tube. The inside cover of the tube is then closed watertight on a rubber joint, and the torpedo remains in that position until shortly before firing. If the necessary adjustments preparatory to firing have not yet been made on the torpedo and it is desired to prepare the torpedo for firing, it is necessary first to pull about six or eight feet of the tail of the torpedo out of the tube. This is sufficient to permit easy access to those parts of the torpedo that require adjustment. The torpedo is then shoved back into the tube and the inner door closed again. Although the middle portion of the torpedo fits the tube very accurately,

it will be realised that there is a large space between the torpedo and the tube at the nose and tail of the torpedo, a space which it requires about 700 lbs. of water to fill. Practically every torpedo attack is made when the vessel is submerged, in which condition it is most important that no alteration to the weights on board should take place. If under these conditions the outer cap of the torpedo tube were opened and the space between the torpedo and the tube permitted to fill, the sudden accession of 700 lbs. weight would not only cause the submarine to sink, but by virtue of its position would give the boat an entirely impossible inclination by the bow. It is therefore imperative that this space be filled before the outer cap is opened, and the water to fill this space must already be on board so that it will be merely a change of position of this quantity of water and no change in the weight of the boat. For this purpose a separate tank, called a filling tank, is usually fitted, containing a quantity of water just sufficient to surround the torpedo in the tube, and to prevent any change in trim taking place it is desirable that this tank should be situated

in approximately the same longitudinal position as the tubes.

When, therefore, it is desired to fire the torpedo, the first operation after the necessary adjustments on the torpedo have been made is to entirely fill the space surrounding the torpedo in the tube by pumping or blowing the water in the filling tank into the tube. The outer cap may then be opened with impunity as no water can enter, consequently no change in weight can take place, and the torpedo is now ready for firing.

The actual act of firing is nearly always performed by the commander of the boat who actuates the firing mechanism with an electric push-button either in the conning-tower or in the central station. The electric gear operates a large valve, the opening of which permits the contents of a tank filled with compressed air at 100 lbs. per square inch pressure to enter the tube behind the torpedo, and the torpedo is ejected from the tube with a speed of about 30 knots an hour. On its way out the tube mechanism engages a lever on the torpedo and pulls it over, starting the engines of the torpedo itself so that the torpedo is self-propelling as

soon as it is clear of the tube. In firing a torpedo, a weight of about 1,600 lbs. in the case of an 18″ torpedo is suddenly released, but the space that the torpedo had occupied is almost instantly filled with sea-water. Now the weight of a torpedo at the moment of discharging is 20 or 30 lbs. more than the weight of a corresponding amount of sea-water, so that the only change in weight that has taken place due to the operation of discharging a torpedo is a loss of 20 to 30 lbs. in weight, representing the difference between the weight of the torpedo and this volume in sea-water. Even this slight difference, however, coupled, of course, with the fact that it takes an appreciable, although fractional, interval of time for the water to occupy the space that the torpedo had originally occupied, is sufficient to give the bow of the boat a tendency to come to the surface. This tendency being well known, however, can readily be anticipated and counteracted by the operator of the diving gear. It has been stated above that the weight of the torpedo *at the moment of firing* is greater than the weight of a corresponding volume of sea-water. This is due to the weight of the compressed air with which the torpedo is

Dutch Submarine 07 Entering Flushing Harbour

charged. As the torpedo runs its course and this volume of air is gradually expended in propelling the torpedo, its weight becomes less, until at the end of the run when the air has all been expended, the torpedo is lighter than sea-water and comes to the surface. This will be dealt with more fully in the section relating to torpedoes.

Now that the first torpedo has been fired, we have to reload the same tube and fire a second torpedo. We have left the tube with the inner cover closed and the outer cover open and the tube full of water. The first operation is to close the outside cover. The filling tank which holds the water to surround the torpedo must first be filled from the water in the tube, and the water which remains in the tube and represents approximately the weight of the torpedo that has been fired, is then pumped or blown into the torpedo compensating tank fitted for the purpose, there to remain as permanently representing the discharged torpedo until a new supply of torpedoes is taken on board. The tube is now entirely empty and the inside cover may once more be opened and the second torpedo loaded into the tube, after which the breach is

closed. The filling water is not transferred from the filling tank to the tube until just prior to firing, as the corrosive action of the salt water on the steel mechanism of the torpedo would cause rapid deterioration. In some of the German submarines that were fitted with broadside tubes, the space around the torpedo was filled with oil to prevent deterioration. This was rather an expensive and unsatisfactory solution of the difficulty, inasmuch as the entire quantity of oil was wasted with every shot, and, in addition, such a quantity of oil rising to the surface before the torpedo was fired would have been of material assistance in indicating the presence of a submarine. This scheme was very soon abandoned.

No modern submarine of reasonable size is built without at least one quick-firing gun as a means of defence against small craft, aeroplanes and dirigibles. The calibre of the gun varies from 2″ to 3″, with a supply of about 100 rounds of ammunition. Some larger submarines are equipped with two such guns. There are two entirely different principles involved in the arrangement of the gun, one of which is exemplified by the U. S. Navy and the

other by the German Navy. In all submarines in the U. S. Navy the gun is fitted in a water-tight box in the superstructure. To bring the gun into firing position, the cover of this box must be opened and the gun raised. In an emergency where it is imperative to submerge within a few seconds, it is quite conceivable that one might dive without taking time to lower the gun and close the cover. This would be a dangerous operation because the container would suddenly fill with water at a moment when the submarine had only a few hundred pounds of reserve buoyancy. The weight of this water would hardly be less than a couple of tons, which might very well be sufficient to send the boat to the bottom unless prompt measures were taken to counteract it by blowing out some of the tanks. Besides, a gun mount which must necessarily be hinged cannot be made as rigid and secure as a permanent foundation.

The German system dispenses entirely with the water-tight box and consists simply of a gun with a hinged mount which houses in the superstructure. When the boat submerges and the superstructure fills, the gun comes in contact

with sea-water, so it is necessary before submerging to remove the breech-block mechanism and the sighting telescope, as these parts would be hopelessly damaged by a contact with sea-water. The newest German boats, for reasons already stated, have abandoned the hinged mount and have adopted a rigid mount for the gun so that it remains at all times above the level of the superstructure deck and is ready for action on a moment's notice as soon as the breech-block and sighting telescope have been fitted in place. They are made easily portable so as to be removed quickly, and it is to be hoped that a supply of reserve breech-blocks is carried on board, for any one with practical experience with submarines will be found prepared to assert that anything and everything portable on a submarine is sure in course of time to go overboard.

In order that the gun fitted above the deck may not offer too much resistance to propulsion submerged and also to prevent its becoming entangled in ropes or nets, a light non-watertight sheet metal casing is built around it which can quickly be opened up and lowered on the super-

structure deck, in which position it forms a working platform for the gun crew.

Up to the present time, and with few exceptions, the arrangements for handling ammunition are rather crude, this being done by hand. There is, however, no engineering reason to prevent suitable ammunition hoists being fitted as soon as the calibre of the guns becomes great enough to make it desirable.

#### PERISCOPES AND RANGE FINDING

One of the most important instruments on a submarine, in fact the eyes of the vessel when running submerged, is the periscope. In its most primitive form it was first introduced into French submarines about fifty years ago, in the form that is now familiar to us as the trench periscope—a simple tube with two mirrors, one at the upper end and the other at the lower end, each inclined at 45° and projecting the image through the vertical tube.

Very little improvement in this primitive but essential device was effected up to the beginning of the twentieth century. At about that time its optical qualities were improved by fitting two triangular prisms instead of mirrors

and by the introduction of lenses which focussed the view in the eye-piece.

It is commonly believed by those not familiar with this subject that the periscope projects a view on a ground glass screen or table similar to a camera obscura. This, however, is not the case. Most modern periscopes are fitted with a single eye-piece which has to be used in the same way as a marine telescope. As the continued use of one eye for hours at a time is optically very tiring, endeavours have been made to substitute a binocular arrangement to be used in the same way as field glasses, but this has not yet been generally introduced. It is true that until recently, in addition to the monocular eye-piece, certain instruments have been fitted with a ground glass screen about 4 inches in diameter, but the illumination was so poor that it had no practical value and it has been generally discarded.

All submarines are now fitted with at least two periscopes, and some with three; the third periscope, known as the zenith periscope, being used for making vertical observations to enable the submerged submarine to detect the presence of aircraft. It has been found desirable to fit

at least two periscopes of the ordinary type not only for the purpose of having one in reserve in case the other is shot away, but also as a measure of safety in submerged navigation. The installation of two periscopes makes it possible for one instrument to be placed at the disposal of the steersman who is looking ahead more or less continuously, while the commanding officer at the other periscope is able to search the horizon in all directions and train the vessel on the enemy without interference with the steersman's periscope.

The instrument itself is a tube about 6 inches in diameter, projecting from 18 to 20 feet above the level of the superstructure deck. As the conning tower has a height of 6 to 8 feet above the superstructure deck, this length of periscope is necessary in order that the top of the conning tower may be sufficiently immersed. Normally in a moderate sea the tops of the periscopes project from 3 to 4 feet above the surface of the water when the vessel is submerged, the after-periscope, which is usually the commander's instrument, being made a few inches longer than the forward or steersman's periscope to give the commander a clear view ahead over the

other periscope. In cases where a third periscope is fitted for observing air-craft, it is the shortest of the three, whether fitted forward or abaft the others.

A feature of the newest periscopes is the reduction in diameter of the upper end from 6 inches to about 2 to 3 inches for a length of 5 to 6 feet. As soon as periscopes were generally introduced, naval manœuvres speedily demonstrated the fact that it was not the periscope that could be detected at long range when the vessel was running submerged, but the periscope wave which caused a very considerable disturbance on the surface of the water and left a trail of white foam behind that could be seen from a long distance. The surface disturbance was very materially decreased without any loss in optical power by the reduction in diameter of the upper part of the tube from 6 inches to 2 inches, and its visibility was still further decreased by painting the periscope with a mottled effect, and in many cases during the present war a dummy sea-gull has been attached to the top of the highest periscope to allay suspicion. It is the visibility of the periscope wave that has made it necessary for sub-

marines to navigate at very slow speed, not over five knots an hour, when on the point of delivering an attack. It has also been found desirable to fit a mechanism for raising and lowering the periscope bodily a distance of 4 or 5 feet. In this way it is possible to deliver an attack with absolutely nothing in evidence above the surface for the greater part of the time. Occasionally the top of the periscope is raised for a few seconds just sufficiently to permit the navigator to correct his observations and is then lowered again. The final observation is made immediately prior to firing and at a range perhaps not exceeding 400 yards, and any final correction in the course of the vessel that may be necessary is made. The periscope at that moment may be detected for the first time. It is usually too late. Whether the shot be a hit or not, the submarine quickly lowers the periscope and changes her course. When the next observation is made, the object of the attack is either retreating at full speed or sinking.

In considering the use of the periscope in making an attack reference is made to only one periscope. This is due to the fact that when

the enemy is at close range, the steersman and his periscope are eliminated and the navigation of the vessel and the execution of the attack devolve entirely upon the commander. It will be evident, therefore, that even if the top of this periscope be shot off, the submarine is by no means hors de combat, for the steersman's periscope can be used equally well to fulfil the functions of the commander's periscope. It is the general practice in most navies to fit both periscopes in such a way that the lower eyepieces come into the central operating compartment or central station, although in some submarines, notably those of the German Navy, one periscope is fitted with its lower eyepiece in the conning tower and the other one in the central station.

The question has often been asked, whether the shooting off of the periscope will not prevent a submarine being submerged because of the water entering the boat through the 6-inch hole made by the periscope tube. The shooting off of the top of any of the periscopes has no effect on the vessel other than the putting out of commission of the damaged instrument. Every periscope is provided at its lower end at a point

inside the hull of the vessel with a plate-glass seal through which the light can readily pass but which effectually prevents the admission of any water. This glass is of sufficient thickness to withstand the pressure due to any depth of submergence at which the submarine can safely navigate. Heretofore, periscope tubes have been made of bronze or of steel with such a proportion of nickel as to be practically non-magnetic because of their influence on the magnetic compass, but with the advent of the gyroscopic compass, the use of non-magnetic material for periscope tubes is no longer imperative. When periscopes were first generally used, about the beginning of this century, a curious difficulty arose for which a practical solution has now been found. The field of vision varies from about 45° to 60°, so that in order to scan the entire horizon it was necessary to rotate the upper prism. In so doing the image as observed through the lower eye-piece also rotated, so that when looking astern the image literally stood on its head, i.e., with the horizon across the middle of the field, the water occupying the portion where one expected to find the sky, and any ship that might be in sight

hung downward with the masts and funnels dependent like stalactites. This effect was very confusing, and in any intermediate position between dead-ahead and dead-astern, the horizon was at an angle which was even more confusing. At first this was improved by installing a correcting lens whereby the horizon remained horizontal, with the sea occupying the lower half of the field and the sky the upper half, but this was found to be almost equally unsatisfactory, as one had no sense of direction. Whether looking ahead or astern or in any other direction, the view was substantially the same, and to ascertain the bearing of the periscope relative to the submarine, one was obliged to consult an indicator fitted in the proximity of the periscope which gave the information required but detracted the attention from the periscope and introduced a serious liability to error. The arrangement now generally in use is one in which the whole instrument revolves bodily and the person observing through the lower eye-piece goes round with the instrument and obtains thereby an accurate sense of direction relative to the course of the boat, which is highly necessary when navigating submerged.

The optical arrangements of the periscope are such that objects are observed at their true distance, and in addition a magnifying lens is fitted which can be brought into position instantly when required, by means of which a magnification of about one to four is obtained. This magnification is utilised for the purpose of reading signals and picking up small objects at long range. The determination of the range of an enemy ship is also effected by means of the periscope. The lower eye-piece is provided with two vertical wires which can be shifted laterally across the field by means of two thumb screws. When the observation is made, the class of the enemy ship must first be determined. This is not so difficult as might appear. Every submarine is provided with a copy of Jane's "Fighting Ships" or a similar book published yearly by the German Admiralty. In these books one finds a black silhouette of every class of naval vessel in existence, along with a short description of the individual peculiarities or characteristics of particular ships and their principal dimensions. It is the duty of every naval officer to recognise the Navy and class to which a vessel belong, if not by memory, at

least by comparison with the silhouettes in these books. As soon as this has been ascertained the length of the ship is also known. By adjusting the two screws operating the vertical wires until one wire corresponds with the bow and the other with the stern of the ship under observation, a reading of the scales which are connected to the screws that operate the wires gives either the range directly or a number from which the range can be established by a simple arithmetical process. There is, of course, an element of inaccuracy in this calculation, as it is based upon the actual length of the enemy ship. This actual length will only be correct, however, when the course of the enemy ship is at right angles to the course of the submarine. If the course is at any other angle, then the apparent length of the ship under observation is less than the true length, and the use of the true length in determining the range would give too great a range. To obviate this difficulty, the course of the ship relative to the course of the submarine must be estimated. Range-finding devices are sometimes fitted in which a vertical measurement independent of the course of the ship, such as

Dutch Submarine 07 Rising After Submerged Run

the height of the funnel or the height of the mast, is used as a basis for measuring the range just in order to eliminate the uncertain factor which enters the calculation when the course of the ship under observation has to be judged.

All of these devices are only approximately correct as compared with the exactitude of the range-finding apparatus fitted on a modern battleship, but it must be borne in mind that accuracy of range is a much less important factor in submarine warfare than it is in the case of a battleship, where the gun is the principal weapon. It will be obvious that the target presented by a ship under gun fire is very much longer than it is in height, so that in order to secure a hit a much higher degree of accuracy is necessary in a vertical than in a horizontal plane. Moreover, the distance at which fire is opened with a gun is vastly greater than the range at which a torpedo is discharged by a submarine. For these reasons, a very accurate means of determining the range is essential for the battleship. In the case of a torpedo attack by a submarine, the possibility of missing the target in a vertical plane is eliminated altogether, and one's attention need

only be devoted to accuracy in the horizontal plane. The torpedo having been previously adjusted to run any desired depth below the surface, rarely fails in this respect, so there is very little chance of the torpedo missing its object because of going under it, and of course no possibility of going over it. The only element in this comparison that militates in favour of the gun and against the torpedo is the comparatively slow speed of the torpedo and the consequently greater time in which any error of judgment has an opportunity to become effective. The torpedo director by which the entire process of firing from a submarine is reduced to a mechanical operation, will be treated in the chapter relating to practical operation.

In conclusion, a short description of the drying apparatus for periscopes may be of interest. If a submarine has been on the surface for some considerable time, the air in the periscopes will have about the same temperature as the atmosphere. If the vessel were then to submerge in water colder than the air, the reduction of temperature of the periscope tube would cause a precipitation of the moisture in the air contained inside the tube, which would ultimately

cover all the lenses and entirely obscure the image. For this reason it is necessary to previously dry the air as completely as possible by passing it through sulphuric acid or through a vessel containing calcium chloride, or some other absorbent of moisture, and then hermetically seal the periscope so that the contained air will remain dry. In practice it is found impossible to seal the periscope so that the air will remain dry for an indefinite length of time. It is therefore necessary to carry an apparatus on board for periodically replenishing the supply of dry air for the periscopes.

It has sometimes been asked if the splashing of sea-water against the upper prism does not obscure the image, and some periscopes have actually been fitted with a small tube through which a current of air could be blown across the outer surface of this prism to keep it dry. It has been found, however, that the splashing of sea-water has very little detrimental effect upon the image as it usually forms a complete film of water over the entire surface of the glass. Rain has been found to be more troublesome than sea-water in this respect, but when rain drops have accumulated on the surface to such

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# CHAPTER VI

## Safety Devices

In the beginning of the Twentieth Century, an element of submarine design, to which primary importance was attached, was the question of safety devices. In some navies so much importance was attached to saving the boat and crew in case of an accident, that the primary function of the vessel as a military unit was almost entirely overlooked. In fact there are many submarines now in existence in which the weight allotted to safety devices exceeds the total weight of the main engines and amounts to three-fold or four-fold the weight devoted to armament. Contemporaneously with these vessels, others were designed and built in which safety devices were practically non-existent and the safety of the boat and crew was permitted to depend upon good workmanship in the case of the former, and vigilance and carefulness in the case of the latter. In

vessels where safety devices were conspicuous by their absence, an accident due to external causes involved inevitable loss of the ship and crew, and those in which safety devices predominated were not much more fortunate when anything really happened, because the multiplicity of arrangements for safety so greatly increased the complexity of the boat that the likelihood of an accident, due to a mistake on the part of the crew, was considerably increased. The tendency in recent years has been in the direction of compromise. Safety arrangements that could conveniently be incorporated in the design and that really were what the name implied and which, moreover, could be employed without impairing too seriously the military value of the boat, have been adopted. The other so-called safety devices, which in many cases were purely fantastic, have gradually been eliminated.

It seems curious that so much prominence has been attached to safety devices in a submarine, while in other vessels for naval purposes, hardly a thought, much less a pound of unnecessary weight, is devoted to saving the crew in case the vessel is sunk, and yet the

sinking of a battleship involves a thousand lives where the sinking of a submarine involves 20 to 30. Of course, the battleship is provided with bulkheads and water-tight compartments as a safe-guard against sinking, but the principal object in so doing is to reduce the risk of losing the ship as a military unit, and the safety of the crew is merely incidental thereto.

When a battleship is sunk, as frequently happens in a naval engagement, only the men on deck have any chance of being picked up. Those hundreds who are locked up in the vitals of the ship go down with her, to sure death.

There is, however, a certain justification for the employment of practical safety devices in a submarine which would not apply in the case of any other type of ship. Practically every member of the crew of the submarine has it in his power to commit an error that might result in the loss of the vessel, and it is this possibility of failure in the human element which must be guarded against as far as possible. Every piece of mechanism in which what is called the "fool-proof" principle can be applied, is so constructed that it can not be operated at all unless operated correctly. But there is a point

beyond which the application of this principle is no longer possible. The intelligence, training and efficiency of the individual members of the crew are then of the highest importance, and safety devices to counteract the effect of possible mistakes which might otherwise be disastrous are essential.

Among the safety devices that are generally incorporated in designs of modern submarines, which may be said to have survived the process of elimination, may be mentioned the following:

A. *Double Hull.* While this was not originally regarded as enhancing the safety of the vessel, advocates of the Double Hull system of construction contended that the presence of a double hull reduced the risk of sinking, through collision, inasmuch as the outer shell must be crushed and the inner hull penetrated before any water can enter the vessel proper. Of course, the crushing of the outer shell would cause the ballast tank to fill, but when the boat is submerged the ballast tank is full in any case, and if the vessel were navigating on the surface the filling of the tank, due to crushing of the outer shell, would not entail the sinking of the vessel as long as the inner hull remained intact.

Theoretically this is true, and it might be practically true also were the outer hull of sufficient thickness to withstand any considerable impact. The outer hull, however, is of very light construction and must necessarily remain so, as otherwise too much weight would have to be allotted to the hull at the expense of the military qualities of the boat. The result is that the light outer shell offers hardly any resistance to impact and in a collision the immunity of the inner hull against penetration is hardly greater than if the outer shell did not exist. In this respect, therefore, there is little to choose between the double hull and the single hull.

B. *Bulkheads.* Until recent years, all American and English submarines have been built practically without transverse bulkheads. On the other hand, German and French submarines have always been built with transverse bulkheads, the value of which in many cases is more theoretical than real. It may be stated as axiomatic that bulkheads actually contribute to the safety of the boat *only* in the case of their being of sufficient strength to stand the full pressure of the sea at any depth at which the submarine may navigate; in other words, they

must be of equal strength with the pressure hull itself. The fatuity of fitting bulkheads that are incapable of standing this pressure will soon become apparent upon analysis:

If the vessel is running submerged and a collision ensues which ruptures the pressure hull, at least one compartment fills with water, and in all probability, before any counter measures can be taken, the vessel sinks to the bottom. If the water is of such depth that the pressure hull itself cannot withstand the sea pressure, the entire hull will be crushed flat, and the presence or absence of bulkheads is immaterial. If the depth is not so great, however, that the pressure hull will be crushed by external pressure, and the bulkheads are of equal strength with the hull, the damage is confined to the one compartment that has been ruptured, and the members of the crew in the other compartments can proceed at their leisure to lighten the vessel by pumping or blowing water out of the undamaged tanks, and if necessary, emptying the fuel tanks and discharging all the torpedoes until enough weight has been ejected to compensate for the weight of water in the damaged compartment and bring the vessel once more to

the surface. It is obvious, that if the bulkheads were not of equal strength with the hull, under these conditions, the pressure of water due to the depth in which the vessel had sunk, would burst the bulkheads and flood the adjacent compartments one after the other, until the entire boat was full.

Take the case of the vessel navigating on the surface, in which the tanks are empty and the reserve buoyancy is at its maximum. If one of the amidship compartments were penetrated, it is conceivable that the additional weight due to the filling of the damaged compartment, would not be sufficient to cause the vessel to sink, in which case even lightly constructed bulkheads, by confining the water to the damaged compartment, could prevent the vessel from foundering. This is a very improbable case, however, and the same collision that damaged one of the amidship compartments would almost inevitably damage some of the main ballast tanks, which would fill also and cause the vessel to sink. The collapse of the weak bulkheads, when subjected to sea pressure, will entail the loss of the vessel as in the previous case.

If, instead of a compartment amidships, one

of the bow or stern compartments were penetrated, with the vessel navigating on the surface, the excess of weight, due to the filling of the compartment, might not be sufficient to bring about the sinking of the vessel, but it would produce a violent change of trim, due to the position of the flooded compartment at the extreme end of the boat. The flooding at one end of the vessel in this way, would depress that end so far below the surface that the bulkheads which confined the water to the flooded compartment would be subjected to the same pressure as if the entire vessel had sunk to that depth. Here again the presence of a weak bulkhead would involve its collapse and the flooding of the adjacent compartments until the flooding and the sinking of the entire vessel resulted.

There is no technical objection to the fitting of pressure bulkheads of equal strength with the hull other than the weight involved, which reduces the weight available for features that might be considered more useful from the military point of view. Where bulkheads are fitted at all, it may now be considered universal practice to fit only pressure bulkheads and these

are provided with double doors and an air-lock between the doors, so that even those members of the crew who are trapped in the damaged compartment have an opportunity to make their escape into one of the undamaged adjacent compartments.

To effect this, each member of the crew is provided with a safety helmet which must be put on in case of accident and by means of which he can breathe for several hours, if necessary, under water.

To pass from a flooded compartment to an undamaged compartment through the air-lock, a valve must first be opened between the flooded compartment and the air-lock, permitting the latter to fill with water and equalising the pressure on both sides of the bulkhead door so that it may be opened. When the door has been opened, one or two of the members of the crew climb into the air-lock and close the door behind them. The valve in the air-lock communicating with the adjacent undamaged compartment permits the water to be drawn off, after which the bulkhead door on the other side of the air-lock can be opened and the men in the lock can step out into the undamaged compartment. In this

way every member of the crew in the flooded compartment, who has not been injured by the collision or otherwise incapacitated, is able to make his escape.

C. *Safety Helmets.* Although there are several types of safety helmets manufactured, they are all similar in general characteristics. A metal casing, like a diver's helmet, covers the head, and a water-tight material covers the arms and upper part of the body, closing tighly around the wrists and waist, to prevent ingress of water. The air contained in the helmet is breathed over and over again, passing through a regenerative chemical which absorbs the carbon dioxide and replenishes the oxygen, the supply of chemical being sufficient to last for several hours. In addition, the device gives the wearer sufficient buoyancy to enable him to float without effort. Every member of the crew is supplied with one of these helmets, which is arranged to be drawn on quickly in case of necessity.

The use of the helmet, in passing from one compartment to another, has been discussed in the preceding paragraph. Its utility in enabling the crew to escape from the sunken vessel,

without external means of assistance, is a much more questionable matter, not, however, because of any inherent defects in the helmet itself. It is customary to fit an escape hatch in every compartment of a submarine, and in those vessels which are provided with double doors in the bulkheads, the air-lock between the doors is sometimes utilised for this purpose. Frequently the conning tower is also fitted up to form an escape hatch. In theory, the operation of the escape hatch is very simple. The escape hatch is provided with an opening on the side giving access into the vessel, and with an opening on top communicating directly with the sea, both openings being provided with suitable covers which can be operated either from inside the boat or from inside the hatch itself. The member of the crew who is endeavouring to escape from the sunken vessel, and to that end is provided with a safety helmet, steps into the escape hatch and closes the door behind him. Before he can open the upper cover communicating with the sea, he must first open a valve which permits the hatch to fill with water, until the pressure inside and outside is equalised, after which the upper cover can be readily

opened and he can climb out. Once free of the vessel, the buoyancy of the safety helmet brings him rapidly to the surface, where he floats in the hope of being observed and picked up. When on the surface, he is not dependent upon the regenerative chemical for a supply of fresh air, as the helmet is provided with a little opening, the cover of which is easily accessible and can be swung open like the porthole of a ship, to give him fresh air. The chance of his being picked up is also quite favourable, if it be known that the submarine has met with an accident. His only difficulty which, however, is a serious one, is to succeed in coming to the surface alive. It is assumed that the depth of water in which the submarine has sunk does not exceed 200 feet. That represents a pressure of nearly 100 pounds per square inch, above atmospheric pressure, which is about the maximum pressure that the average human being can survive.

The individual who is endeavouring to escape from the sunken submarine is labouring under the same conditions as an ordinary diver who has to descend to an equal depth. While in the boat, he is breathing air at practically atmos-

pheric pressure. Before reaching the surface, however, he must subject himself, in the escape hatch, to the full pressure due to the depth of submergence, and then again to the reduction of that pressure from 100 pounds per square inch to atmospheric pressure. If this could be done quickly, there would be no difficulty at all. It is not generally realised that a diver, when descending to any great depth, has to accustom himself, very gradually, to the increase in pressure, and conversely, when ascending to the surface, he must accustom himself to the reduction in pressure. To neglect this precaution would be instantly fatal. The operation of descending from the surface to a depth of 200 feet occupies from two to three hours, and in rising from that depth the same length of time is required.

In escaping from a submarine, the man in the escape hatch is in a position analogous with the diver. Before the upper cover can be opened, he must permit the hatch to fill with water until the internal pressure equals the external pressure, which in his case will also occupy two to three hours. Having accustomed himself to this pressure and freed himself from

the submarine, the same length of time must be occupied in coming to the surface, if dangerous results are to be avoided. This seems to be too much to expect of a man who has just experienced a serious accident and who knows, moreover, that perhaps a dozen men are in his compartment, waiting for their chance to escape. As now constructed, the escape hatches are barely large enough to accommodate two at a time, and the safety helmet has no arrangement which will permit its wearer to regulate the speed of his ascent to the surface, had he the presence of mind to do so. I believe there is no case on record of an escape from a sunken submarine by means of the safety helmet, nor is it likely to be of much practical use for that purpose, excepting in a case where the submarine is sunk in shallow water. It is undoubtedly true that the use of safety helmets along with various other safety devices of doubtful utility has been brought about by the pressure of public opinion, and public opinion has been satisfied with the knowledge that these so-called safety devices were present, without knowing or having the opportunity to know, that their practical value is largely illusory.

D. *Safety Keel.* In European navies, expert opinion is practically unanimous in favour of the safety keel. This is simply a flat keel, having a depth of about 12 inches and a width of about 24 inches, the length being dependent upon the weight desired, which is built up of steel plate and angles and filled with lead. It is made either in one or two pieces and is fitted amidships on the underside of the boat in such a way that it can be released instantly, upon a given signal, by an easily operated mechanism, in case of an emergency. The weight of such a keel varies from 5 to 20 tons, depending upon the size of the boat, and its release tends to bring the submerged vessel immediately to the surface. As a certain amount of what may be termed fixed ballast is essential in any submarine, in order to adjust the longitudinal trim, there seems to be no valid reason for not putting it in some form that can be turned to account, in case of an accident, although this particular safety device has never been adopted to any extent in the United States Navy. The only feature of the safety keel that requires careful consideration from the constructors' point of view, is the releasing mechanism. It

must be practically infallible, but at the same time it must comply with conditions which are somewhat incompatible. There must not be the remotest possibility of the keel being dropped inadvertently. In that way it might easily, almost certainly, cause the destruction of the boat, which would no longer be capable of submergence. On the other hand, the releasing gear must be built more or less on the hair trigger principle so that nothing can interfere with its instantaneous action in case of necessity. From the nature of things, it is not a piece of mechanism that can be tested at frequent intervals to insure its satisfactory operation at the critical moment. In fact, it is really only when the boat is in dock that it can be tested at all. To satisfactorily fulfill these rather conflicting requirements has supplied the constructor with a very nice problem and it is, undoubtedly, these contradictory elements that are responsible for the divergence of expert opinion as to its practical utility.

E. *Multiple Blowing and Pumping Stations.* Every tank in the boat is provided with a connection to the storage flasks containing compressed air, with control valves to permit any

Dutch Submarine Half Speed on the Surface

or all of the tanks to be blown empty by compressed air if so desired. Likewise, there is a connection from every tank to one or more of the various ballast pumps, to permit the tanks to be pumped empty in case the supply of compressed air is low, or in case it is desired to conserve the air supply. For the sake of simplicity in operation, the control valves admitting air to the various tanks, or connecting the tanks to the water piping, are grouped close together in one compartment. Since pressure bulkheads have been generally introduced, it has been realised that this arrangement, although satisfactory in itself, was not sufficient. If the compartment containing these control valves should, perchance, just happen to be the compartment flooded by an accident, the entire system of valves, by means of which the tanks might be blown empty, would be inaccessible and the members of the crew in the other compartments would be helpless, without any means of lightening the vessel or bringing her to the surface. At the expense of a considerable increase in the amount of piping required, and consequently, increase in complication, these control valves are now generally fitted in not

less than three compartments, so that no matter what compartment is flooded there are always two other compartments from which the blowing or pumping of the various tanks can be effected.

F. *Telephone Buoy.* One or two of these buoys are fitted in the superstructure with a releasing mechanism in every compartment. In case of accident, either or both of these buoys may be released, and from their buoyancy will float to the surface and indicate the position of the sunken submarine. To render them visible at night, an electric light is usually fitted, and in the daytime a striking mechanism inside the buoy, operated electrically from the battery in the boat, produces a sound that can readily be heard at the receiver of a submarine signal apparatus. When one of these buoys has been found and the submarine located, communication may be established with the submarine by means of a telephone inside the buoy.

Although listed under safety devices, the telephone buoy is not used exclusively for that purpose, but is also used when the boat is on active service and lying on the bottom, to communicate with the surface.

G. *Submarine Signal Apparatus.* Nearly all submarines are now fitted with the submarine bell signal apparatus, or in the case of more recent boats, with the Fessenden Oscillator, which is an improved means of transmitting signals under water. Sound waves under water are transmitted at a speed of about 4700 feet a second, which is nearly four times as fast as in air. The submarine bell is, as the name indicates, a submerged bell with a pneumatically operated hammer. The strokes of the hammer are controlled by a Morse key, similar to an ordinary telegraph transmitting instrument. The strokes of the hammer on the bell produce sound waves which are transmitted under water for a distance of 10 to 15 miles, depending on weather conditions. Any other vessel fitted with the appropriate sound receiving apparatus will detect the vibrations which are transmitted by a microphone to an ordinary telephone receiver in the hands of the listener. The distance and direction of the ship from which the message emanates may be judged with considerable accuracy by the intensity of the sound heard in the receiver. It is more especially in regard to the direction from

whence the sound comes that room for improvement remains.

The Fessenden Oscillator is a flat steel plate about 30 inches in diameter, fitted in the side of the ship under water in which vibrations of very small amplitude but very high frequency are induced by an electrical apparatus fitted for that purpose. One of these plates is fitted on each side of the vessel near the bow. Its operation is likewise controlled by a Morse telegraph instrument which alternately sets up and interrupts the vibrations in the steel plate by closing and opening the circuit. And the message is transmitted under water in the same way as an ordinary telegraph message.

The submarine signal apparatus, like the telephone buoy, is not limited to its use as a safety device, but forms an essential part of the ship's means of external communication.

H. *Wireless.* The great problem for fitting a satisfactory wireless installation to a submarine is the one of masts to support the antennæ. On ordinary vessels where fixed masts are fitted, this is not a problem at all. But a fixed mast of any height on a submarine offers far too much resistance to submerged propulsion

to be considered, and in any case the difficulty of bringing the connections through the hull of the boat with the vessel submerged without short-circuiting, is still unsolved. Nevertheless, the desirability of being able to transmit wireless messages while submerged is apparent. Up to a range of 10 to 15 miles submarine bell signals serve very well for this purpose, but that is not to be compared with the range of 200 to 300 miles that is attainable with a very simple wireless installation. Experiments have been made with various forms of telescopic and folding masts, but a practical arrangement for mounting and dismounting the out-board part of the wireless installation, which can be operated from inside the vessel, without requiring the presence of any of the crew on deck, is a problem that remains to be satisfactorily solved. Where a number of submarines are operating in conjunction, but separated by many miles, as is the case now with the German submarines operating on the coast of Great Britain, the desirability of coming to the surface, transmitting a message and disappearing again very quickly, if necessary, can easily be imagined.

I. *Automatic Blowout.* The automatic blowout valve is a device which is automatically operated if the vessel accidentally exceeds a predetermined depth, in which case air under high pressure from the air storage flasks is admitted into the main ballast tanks to blow them empty and bring the vessel to the surface. It can be adjusted in advance to any desired depth and has, at least, the advantage over the drop keel that it can be tested at frequent intervals. On the other hand, it is much more likely either to operate prematurely or not at all, and in any case is less positive and slower in its operation than the safety keel.

J. *Fuel Blowing and Pumping Connection.* It is now customary to fit the fuel tanks with pipe connections by means of which the entire contents of the fuel tanks can be blown or pumped overboard in order to lighten the boat, in case of an accident. As the quantity of fuel carried may amount to from 7% to 10% of the total displacement of the vessel, the possibility of emptying these tanks is of great importance. In order to blow the tanks empty, if the vessel has been sunk, it is, of course, necessary to construct them of equal strength with the hull

proper. Otherwise the effort to blow the tank empty would be more likely to burst the tank than to discharge the fuel overboard.

K. *External Connections for Blowing Tanks.* External connections, to which divers can attach an air hose, are frequently fitted to enable the various tanks to be blown empty by compressors on a salvage vessel. These external connections would only be resorted to in the event of the air supply of the sunken submarine being exhausted and the pumping lines so damaged as to be incapable of further use.

L. *Lifting Eyes.* Practically all submarines up to a thousand tons' displacement, are fitted with two or four lifting eyes in the superstructure, for the purpose of permitting a salvage ship to attach tackle for lifting the vessel, when all internal means of raising her are unavailing. The utility of the lifting eyes depends entirely upon the presence of a suitable salvage ship capable of handling the tremendous weight, which, even under the most favourable circumstances of wind and weather, is an exceedingly difficult operation. In some cases, as in that of the German U-3, where the vessel was lying in shallow water, the lifting eyes may

be used to raise one end of the vessel while the other end remains on the bottom. In the case of the U-3, 24 men escaped through the torpedo tubes, the three men in the conning tower being lost.

M. *Detachable Boat.* Of all the various fantastic devices invented for saving the crew of a sunken submarine, probably none has gone through more variations than the idea of a detachable boat or buoy of sufficient size to contain the entire crew, which, upon being released, would rise to the surface. While technically it is by no means an impossible accomplishment, it can only be done at such a sacrifice of military value and efficiency that the idea has never been put into practice in any modern submarine.

# CHAPTER VII

## Practical Operation

In surface navigation, there is nothing essentially different between a submarine and an ordinary vessel. So this chapter will be devoted particularly to those characteristics and requirements that relate to navigation submerged.

When the vessel is navigating on the surface and the order is given: "Prepare to submerge!" the various hatches and outboard openings are carefully inspected to make sure they are properly closed. The closing of the conning tower hatch is deferred until all the members of the crew have gone below and taken up their stations. Bulkhead doors are all closed, extension ventilators pulled down and depth gauge connections to the sea opened.

Assuming that all torpedoes are on board or that the compensating tanks therefor have been previously filled, the first command is: "Fill

the main tanks!" If the main engines have not been previously stopped, they are immediately shut down when this order is given. The couplings connecting them with the main shafts are withdrawn and the valves in the exhaust pipes are tightly closed to prevent water entering the cylinders. If there is anything dramatic to the novice in the entire proceeding, it is probably at this moment, when the command, "Fill the main tanks!" is given, when the swirling and rushing of the water through the valves in the bottom of the boat and the escape of air through valves in the upper part of the tank can be distinctly heard. Seventy or eighty seconds later a curious gurgling sound proclaims the fact that the main tanks are full, which is confirmed by testing the tank at various points to make sure that water is flowing and that no air is present. This is an important precaution as the presence of any considerable quantity of air in the tank that might leak out when running submerged and be replaced with water would constitute an unforeseen and unknown increase of weight in the boat that might readily cause serious trouble. If the longitudinal trim of the vessel at this point is not quite satisfac-

tory, which the commander can judge at a glance at the trim indicator, water is admitted into the forward or aft trimming tank, as the case may be, or pumped from one into the other until it is adjusted. That at least is the proceeding in time of peace. Under war conditions care is taken while navigating on the surface that the trim will be approximately correct. Moreover, it can always be corrected when the vessel is submerged.

The next command is: "Fill the auxiliary tank!" The commander knows by the number of men aboard, the amount of provisions remaining, and the density of the sea-water approximately how much water will be required in the auxiliary tank. When it nears this point, the valve admitting water to the tank is partially closed to reduce the rapidity of flow. When the buoyancy of the vessel has been reduced to a few hundred pounds and nothing more projects above the surface than the top of the conning tower, the vessel is in what is known as diving trim. The time required to attain diving trim from the moment when the order is given: "Prepare to submerge!" may not be more than 3 minutes, depending to a large

extent upon the size of the valves that admit water to the main tanks and on the size of the air escapes from those tanks.

With the vessel in diving trim, the next command, which may be given verbally if the control gear is in the central station or by telegraph if the control gear is in the motor compartment is: "Both motors ahead, half speed!" Then: "Dive to 20 feet!" The time required for this operation depending on the speed of the boat and the nature of the sea is 15 to 30 seconds.

Where haste is necessary, the entire transition from running on the surface at full speed under the Diesel engines to running submerged at a depth of 20 feet can be performed within 3 minutes.

When the command: "Dive to 20 feet!" is given, the operator at the diving wheel moves the horizontal rudder down until it is 10 or 15 degrees below the horizontal position. The thrust of water from the propeller against the inclined plane formed by the horizontal rudder tends to lift the stern of the boat and depress the bow until the inclination is 5 or 6 degrees, at which juncture the pointer on the depth gauge indicates that the vessel has left the sur-

face and is approaching the predetermined depth. Before the depth of 20 feet is reached, however, the diving rudder operator must shift the horizontal rudder back not merely to the horizontal position, but to a considerable angle above the horizontal position in order to check the downward tendency of the boat and bring her into a horizontal position at the required depth. To do this expeditiously is entirely a matter of skill and experience on the part of the operator. Where bow rudders are fitted, operated by a separate hand wheel, they are frequently used to assist in the operation of diving, but when once the boat is submerged are set horizontally and remain so during the submerged run.

Vessels of the "even keel" type, which are fitted with two pair of hydroplanes and in addition the rudders aft, are intended to submerge by causing the vessel to move bodily downwards with the axis remaining horizontal, and the diving rudders are presumably only for the purpose of counteracting any tendency to depart from the horizontal position. In practice, as has already been explained, the submergence of the "even keel" submarine is much facili-

tated by using the diving rudders as diving rudders and permitting the vessel to submerge with a certain inclination of the axis against which proceeding there is no sound objection. The command: "Dive to 20 feet!" is the one usually given (in the case of European submarines "Dive to 60 decimetres") as this is the depth at which submarines generally navigate with the tops of both periscopes above the surface. But the procedure is exactly the same if one dives to 50 feet or 100 feet or any depth to which the boat can be safely submerged.

When the order: "Rise!" is given, the horizontal rudder is raised a few degrees above the horizontal position, causing the stern to be depressed and the bow to be elevated at an angle which is not permitted to exceed 5 or 6 degrees and the vessel is propelled rapidly to the surface. In running submerged it would be possible to keep the axis of the vessel exactly horizontal if she were entirely symmetrical and had no buoyancy. The resistance caused by the conning tower and the periscopes on the upper side of the boat, which is not balanced by any similar object on the under side, produces a tendency to depress the stern and raise the bow,

which would soon bring the vessel to the surface. In addition to this factor there is a buoyancy of several hundred pounds which is not entirely destroyed by water ballast that is continuously exercising the same tendency. To offset these two factors, the diving rudder operators must so control the vessel that the bow is slightly depressed and the axis is inclined from one to two degrees. With this slight amount of obliquity, the vessel can then navigate submerged on a course parallel to the surface of the water in a state of comparative equilibrium without having any tendency to dive deeper or to rise. It may be said, however, that this state of equilibrium is an unstable one and can only be maintained by vigilance on the part of the diving rudder operator.

The command: "Both motors, half speed!" for diving, could just as well have been: "Both motors, full speed ahead!" as far as the operation of diving is concerned. For the purpose of conserving the store of electrical energy, however, it is not customary to operate under any circumstances except under those of emergency or necessity at more than half speed. The minimum speed, however, at which the boat

can be submerged, as has been already explained, is about 4 knots.

The speed desired is determined, of course, by the commander and is given verbally to the electricians expressed in amperes of electric current. That brings one to the question: What is the "speed" submerged? When this question is asked concerning an ordinary vessel it is always the maximum speed that is meant and probably the same thing is intended in regard to a submarine. The term "speed," implying maximum speed, is rather illusory in connection with the submarine as it is hardly ever employed and when employed will exhaust the fully charged battery in an hour. In fact, the maximum speed of the boat is determined entirely by the rate at which it is possible to discharge the battery, assuming of course that the electric motors are big enough to sustain such a load. It has been found by practical experience that one hour is the minimum time in which a battery can be discharged without excessive heating and consequent damage and deterioration of the plates. The speed of a submarine at the maximum discharge rate of the battery is from 11 to 12 knots for one hour only,

after which the battery is practically exhausted. Again the question is frequently asked: "How long can a vessel remain submerged?" There are several factors that determine the length of time a vessel can remain submerged, one being the supply of electrical energy and another the supply of fresh air. As the supply of fresh air will very much outlast the supply of electrical energy, if the vessel is lying idle at the bottom not consuming any electrical energy other than what is required for lighting, it is obvious that she will be able to remain submerged much longer than if under way. The maximum length of time a vessel can remain underway submerged is determined by the capacity of the battery at the minimum speed at which the vessel can be controlled under water. This speed, as heretofore stated, is about 4 knots, which can be maintained for 20 to 25 hours. Both in regard to the maximum speed submerged and the maximum endurance at the minimum speed no discrimination has been made between large and small boats, for the reason that there is no distinction in that respect. Any difference that may exist between a small boat and a large boat is due either to different types of battery being

employed or to the fact that one boat is of more recent date than the other. There are undoubtedly many people who have been told or read that the maximum speed of a submarine submerged is 11 to 12 knots and the maximum endurance 20 to 25 hours who are under the impression that a speed of 11 to 12 knots can be maintained for a period of 20 to 25 hours. The whole question of speed and endurance submerged is very much like the problem of how long it will take to spend a thousand dollars. One can spend it all at once in a very short time or expend it very sparingly over a long period. There are, however, two practical limits in the case of the submarine, the maximum speed being determined, as already indicated, by the maximum rate at which the battery can be safely discharged, and the maximum endurance submerged being determined by the minimum speed at which the boat can be navigated. There is one important and very curious respect in which the analogy between the thousand dollars and the battery does not hold. The capacity of the battery is not a fixed amount, but varies with the rate at which it is consumed. The higher the rate the less the capacity and

vice versa. In fact, no definite figure for the capacity of a battery has any meaning unless the rate be specified at the same time. To give a concrete idea of how important a factor this is, let us take the arbitrary figure of 100 as representing the capacity of a battery at the 3 hour rate. The sub-joined table will indicate the capacity of the same battery at varying rates of discharge:

*CAPACITY*

| | | | | | |
|---|---|---|---|---|---|
| 69 | at | the | 1 | hour | rate |
| 100 | ” | ” | 3 | ” | ” |
| 111 | ” | ” | 5 | ” | ” |
| 127 | ” | ” | 10 | ” | ” |
| 139 | ” | ” | 20 | ” | ” |

From a casual examination of this table it will be seen that the capacity of the battery at the 10-hour rate, by which is meant the total quantity of current that can be obtained from it measured on the meter, is nearly double its capacity of the 1-hour rate. Nothing more is needed to emphasise the importance of running at a slow speed submerged in order to secure the advantage of this curious characteristic of a storage battery.

If we apply the analogy of the expenditure of a thousand dollars to the discharge of the battery, we find that our thousand dollars is only a thousand dollars if expended in 3 hours. If expended in one hour it becomes only $690; if expended however in 10 hours we find that we have $1,270. It is not necessary to examine the relation between these figures and actual electrical units, as the figures are only intended to show the ratio of the capacity at varying rates of discharge, and this same ratio obtains, regardless of whether the battery contains one cell or 100 cells, or whether the cells are the smallest or largest type.

From the military point of view, a very serious defect in connection with the use of the storage battery, which, however, is inherent and inseparable from the use of a storage battery, is the necessity for recharging it. Naturally, the source of power must come from somewhere, otherwise the problem of perpetual motion would be already solved, and in this respect the charging of the battery is comparable to recoaling or re-fueling a ship; with this difference, however: that the new supply of electrical energy, for the procuring of which a minimum

of four to five hours' time is required, may be entirely consumed in the same length of time, or, for that matter, in an hour; but with the utmost economy cannot be prolonged more than twenty to twenty-five hours.

The submerged endurance of a submarine when not under way, when no demand is being made upon the stored electrical energy other than for illumination, is determined by the air supply, or more correctly, by the volume of free air in the boat. Without replenishing or refreshing this quantity of air in any way, it has proven sufficient for a period of twenty-four hours. This is much longer than would scientifically have been thought possible, judging by the quantity that medical experts had determined as being the essential minimum to sustain life. In theory, a portion at least of the supply of compressed air in the storage flasks may be used to refresh the air and so prolong the endurance beyond a period of twenty-four hours, but this expedient is seldom resorted to as the conservation of the supply of compressed air for purposes of submerged navigation must not be lost sight of, and under normal circumstances an endurance of twenty-four hours is

more than sufficient. Moreover, without any deliberate attempt to refresh the air in the boat from the air in the storage flasks, a certain amount of the compressed air finds its way into the boat through the leakage in the different joints and valves in the high-pressure air piping, which cannot be made absolutely airtight under the tremendous pressure of 2,500 lbs. per square inch to which they are charged.

As has already been explained under the section dealing with the air regenerating system, most of the German boats, and a few of the French, have an arrangement installed for the revitalisation of the air by means of which the submerged endurance is prolonged to about seventy-two hours. The only useful purpose that this serves is to prolong the length of time the vessel may remain on the bottom or, in case of accident in which the boat cannot rise to the surface, the possibility of sustaining life for a longer period. Generally speaking, an accident of such a character that the vessel cannot be raised within twenty-four hours will prevent her being raised at all by any efforts on the part of her own crew. Where a salvage vessel or some other external means of assistance must

be relied upon, it rarely occurs that the sunken submarine can be located and brought to the surface within the three days' limit of the air supply. The vessel has, of course, the possibility of recharging her own air supply by means of the high-pressure compressors, but for this purpose she must necessarily be on the surface and the operation takes at least four to five hours.

One may ask, "If it takes so long to recharge the storage flasks and that is considered objectionable, why not install a larger compressor and do it more quickly?" While there is no mechanical objection to the installation of a larger compressor, practical limitations of space make it inexpedient. Moreover, it is considered that as four to five hours' time is required in any case for charging the battery, regardless of how powerful the generator may be, and the air flasks can be recharged at the same time the battery is being charged, there is little to be gained by economising time in the charging of the air flasks. It has been said that in submerged navigation, the depth is entirely controlled by the diving rudders, and that by means of these rudders the vessel can be navigated at any depth within the safe limit of submergence.

Two questions that have often been put immediately come to mind. One question is, "Why cannot a submarine go to the bottom in any depth?" The other is, "How far will it go before the 'pressure' stops it?" To those who understand why a submarine cannot go to the bottom in any depth, an explanation will seem superfluous. To those who do not understand, it is difficult to explain. Without going into the hydrostatics of the matter, it may be said that any object submerged in water is subjected over its entire surface to an external pressure, which varies with the depth, the degree of which pressure is measured by the weight of the column of water between the submerged object and the surface. As the height of this column of water varies in direct proportion to the depth at which the object is submerged, the external pressure likewise varies in direct proportion to the depth of submergence. The external pressure on an object submerged in salt water is 2½% to 3% greater than on the same object submerged in fresh water, because salt water is 2½% to 3% heavier than fresh water. In concrete figures, the external pressure on a submerged object is about 45 lbs. per square inch

for every 100 feet of depth. If the submerged object is a solid, it is naturally not affected by external pressure, but if it is a hollow object, like a submarine, which in comparison with its size is hardly thicker than an egg shell, the crushing effect of the external pressure can readily be imagined. On a vessel of 800 tons submerged displacement the total amount of external pressure tending to crush it flat will be in the neighbourhood of 155,000,000 lbs. at a depth of 300 feet. As this pressure would be increased in direct proportion to any increase in depth, it will be obvious that a point would soon be reached at which it becomes practically impossible to construct a vessel of sufficient strength to withstand the external pressure and leave any weight at all available for motive-power, armament, etc. In practice it is deemed sufficient to build a boat of sufficient strength to descend safely to a depth of 200 feet with a factor of safety of two. The expression "factor of safety of two" means that at the depth of 200 feet the stresses in the structure are only one-half of what is considered dangerous. At a depth of 400 feet, the stresses are such that the vessel would be on the point of collapse. It

must be understood, however, that this pressure is exerted equally on all parts of the surface of the vessel and exerts no tendency whatsoever to retard either her rising or her sinking. It merely varies in intensity as the depth of the vessel below the surface varies. From the foregoing it will be evident that the pressure has no tendency to arrest the submergence at any depth; consequently, if the vessel will sink at all, she will sink utterly to the bottom, whatever the depth may be. There is just one condition which is very rarely met with, in which it is conceivable that a submarine may descend to a certain depth and there remain, so to say, in a state of suspension, i. e., when the density of the water due to a higher degree of salinity is greater below the surface than on the surface. If under these conditions the vessel is carefully trimmed so that the buoyancy is entirely destroyed and a few pounds' excess weight of water ballast is admitted, the vessel will slowly sink until she enters a stratum of water of greater specific gravity containing a higher percentage of salt, which may be just sufficient to prevent the vessel sinking any further. There, as she has no tendency to rise, she will

remain until conditions are changed. It sometimes happens with varying currents, especially off the mouth of a large river, that a stratum of fresh water will be found on the surface where the underlying water is of greater density. It just as frequently happens, however, that the reverse is the case and that the vessel navigating at a certain depth suddenly enters a current of fresher water than the water in which she was trimmed for diving and encounters a strong tendency to sink, which can only be counteracted by the diving rudders or by discharging some water ballast. While it is hypothetically possible that a submarine may remain suspended at a certain depth below the surface because the submerged submarine in any case has almost the same weight as water, this is not and can never under any circumstances be true of any ordinary ship, which inevitably must go to the bottom in any depth if the buoyancy has once been destroyed to a sufficient extent to prevent flotation.

"How far can one see under water?" is another question that interests the uninitiated. Also, "If the presence of a submarine may be detected by the periscopes, why not navigate

submerged without periscopes and find your enemy by using a searchlight?" It has probably never been determined with exactitude how far one can see under water, but it is naturally dependent on one's power of vision and on the clarity of the water. In any case, it is such a short distance, under the most favourable circumstances, as to be of no practical utility. Navigating in a submarine that had been painted white, in the Mediterranean, in water as clear as the proverbial crystal, and on a sunny day, it was just possible, looking through the ports of the conning tower, to discern the bow of the submarine distant about 60 feet. The searchlight would hardly improve matters even were there a supply of electrical energy on board to keep it burning for any appreciable length of time, and quite apart from the fact that the rays of a searchlight emanating from a submarine would be much more useful to the enemy in his efforts to locate and destroy the submarine or to escape.

"Can the crew easily stand the pressure in the boat when submerged?" is a query in which many are interested. This can most readily be answered by stating that there is no pressure

worth mentioning when submerged. With the boat on the surface and the hatches open, the pressure inside is, of course, the same as atmospheric pressure, i. e., it varies from 28″ to 31″ on the barometer. This is the pressure to which we are all accustomed, which is not considered pressure at all. The mere act of closing the hatches on a submarine does not bring about any alteration in the internal pressure. In the course of a long submerged run, there is a slight increase in pressure due to the leakage of air from the air-flasks, and to the exhaust of some of the auxiliary machines, such as cylinders for raising and lowering periscopes, or for opening torpedo tube caps or similar devices that are pneumatically operated. In filling certain of the smaller tanks, the air in the tank is sometimes permitted to escape into the boat, which likewise tends to increase the pressure, which at the most, however, does not exceed a few inches on the barometer and takes place so gradually as to be unnoticeable. Moreover, an escape valve fitted in the hull for the purpose, prevents the accumulation of any excess pressure to an extent that might be disagreeable. It might sometimes happen that this increase in

internal pressure would take place when it was obligatory to remain on the bottom of the sea, under which conditions the sea-pressure would prevent the escape valve from functioning. This state of affairs is very easily remedied by running the high-pressure air-compressor for a few moments, drawing the air from the boat and pumping it overboard until the pressure in the boat is again reduced to normal. A special barometer, reading up to about 38″, is generally fitted so that the exact control of the air pressure in the boat is entirely within the power of the crew. The only moment during which one feels any effect whatsoever from the difference in pressure inside the boat and externally, is when the first hatch is opened when the vessel comes to the surface after a long submerged run. The escape valve is incapable of equalising the last fractional difference in pressure because of its own weight, but as soon as a hatch is opened, an almost instantaneous equalisation of pressure takes place, which for a few seconds produces a curious feeling in the eardrums.

In running on the surface under the Diesel engine, if the weather is very rough, it is sometimes necessary to close all the hatches and the

Dutch Submarine 07 Full Speed on the Surface

only source of supply of fresh air for the engines is through the ventilators. As it is not practically feasible to make the ventilators large enough to supply the enormous quantity of air consumed by the engines without an appreciable drop in pressure, there is a slight reduction in internal pressure when the boat is running in this condition which does not tend to increase, however, but soon reaches its maximum and continues at that point, producing no disagreeable results. Here again, when the engines are stopped, the sudden equalisation of pressure causes the same sensation to the eardrums as when the first hatch is opened after a submerged run.

I have frequently been asked to describe the sensation in diving. Although at such a slight angle there is not very much of a sensation to describe, it seems more nearly comparable to the feeling experienced in a cable car going over the brink of one of those steep hills in San Francisco than to anything else. In a boat without bulk-heads where one has a view throughout the entire length, any slight change in longitudinal inclination is immediately perceptible, and the degree of the angle can be judged quite

accurately. In submarines fitted with bulkheads, however, in which the internal space is divided up into comparatively small lengths, those members of the crew who are not in the central station and cannot, therefore, observe the depth gauges, are hardly aware of whether the boat is submerged or on the surface. In either case, the illumination is entirely by electric light, so the absence of daylight gives no indication of what the vessel's position may be. Considerable longitudinal inclination of the boat is hardly noticeable in the short compartments.

The number of the crew in a submarine is, of course, dependent upon her size, but it may be said that a submarine of 800 tons requires a crew of three officers and twenty-one men. Although technically described as "men," the majority have the rating of petty officers or warrant officers, as a high degree of skill and intelligence is required, and very few of them are ordinary sailors. The number of compartments varies in different sizes and different types, but the average submarine of 800 tons' displacement would have about seven compartments inside the pressure hull. A list of these

compartments beginning from the bow is subjoined:

1. Bow torpedo compartment containing officers' accommodation.

2. Forward battery compartment—above battery, crew's living space.

3. Central station.

4. After battery compartment—above battery, crew's living space.

5. Engine room.

6. Main motors and auxiliary machinery.

7. Torpedo compartment, if stern tubes are fitted.

When running submerged, the majority of the crew is on duty, apportioned among the various compartments approximately as follows:

1. Bow torpedo compartment: 2 torpedo gunners, 1 mechanic.

2. Forward battery compartment: none.

3. Central station: 1 captain; 1 first officer; 1 steersman; 2 diving rudder operators; 2 electricians, 1 mechanic handling air valves; 1 mechanic for handling water piping valves; 1 mechanic handling valves for flooding ballast tanks.

4. After battery compartment: none.

5. Engine room: none.

6. Main motors and auxiliary machinery: 2 assistant electricians and oilers.

7. Stern torpedo compartment: 2 torpedo gunners.

In surface navigation only 8 men are required, as specified hereunder:

1 commanding officer
1 steersman
2 engineers
2 oilers
2 deck hands

In this way the crew of 24 is able to work in 3 shifts of 8 hours each for long cruises on the surface.

When engaged in torpedo practice submerged or in firing at an enemy ship under war conditions, the torpedo director plays an important rôle. The torpedo director is nothing more or less than a mechanical calculator which performs accurately and quickly a calculation that would otherwise have to be made mathematically, with the consequent risk of inaccuracy, especially in circumstances where haste is essential. In the section dealing with torpedo

tubes, it has already been explained how torpedoes are loaded into the tubes and fired, and the section relating to periscopes has dealt with the method of finding the range of the enemy ship. Having ascertained the range, which forms one of the elements of the calculation to be solved by the torpedo director, the speed of the vessel under attack must be estimated. When the various adjustments have been made in the torpedo director, corresponding to the estimated factors of the speed, range and course of the enemy ship and the known factors of the submarine's course and speed, the cross-wires in the periscope are shifted to a certain position which represents the mechanical solution of the problem. In other words, if none of the factors, either known or estimated, change in the meantime and if the estimated factors have been judged with sufficient accuracy, the pressing of the button that fires the torpedo at the moment the enemy ship crosses the wire in the field of vision in the periscope will insure the torpedo's striking the ship. There is, of course, the further possibility that a defective torpedo may not follow an absolutely straight course, but that occurrence is so infrequent in

a modern torpedo in good working order as to be negligible. The only reason why a hit is not inevitable is the fallibility of the human factor in misjudging the range, speed or course of the ship attacked and the contingency, which must necessarily be unforeseen, of the ship changing either her course or speed during the operation. As a rule, if the submarine has not been observed, there is little likelihood of either course or speed being altered sufficiently to materially affect the result.

It has frequently been asked if a torpedo can be fired when a submarine is on the surface. Even when the vessel is on the surface, the torpedo tubes are generally under water, but in any case, whether under water or above water, there is no technical reason to prevent the torpedo being fired. Militarily speaking, however, there are hardly any circumstances conceivable, except in torpedo practice, when torpedoes are fired with the vessel on the surface.

Having finished our submerged run, the command is given to "rise." This is never done under any circumstances, except those of an emergency, by expelling water from the ballast tanks, but is always accomplished by the rud-

ders. When the vessel is on the surface, the water may be expelled from the tanks either by blowing it out through the valves in the bottom of the boat with compressed air from the air storage flasks, or by pumping it out.

The objection to emptying the tanks while the boat is still submerged is due to the greater amount of power that must needlessly be consumed. It the tanks be blown out, the pressure of the air utilised must be in excess of the pressure of the surrounding water against which the water in the tanks must be expelled. As the external pressure is at a minimum when the boat is on the surface, it follows that the air pressure required to expel the water from the tanks will then also be at a minimum. For the same reason, the electric motors driving the ballast pumps will consume more power to pump out water when the boat is submerged than when it is on the surface. In the German boats, water ballast pumps for emptying the tanks have practically been dispensed with and their place has been taken by low-pressure air-compressors which pump air into the tanks and expel the water through the valves in the bottom, in the same way as when the tanks are

blown out, except that no demand is made upon the supply of compressed air. It has the additional advantage of requiring much smaller pipes and valves than a pumping system, but it has the very serious disadvantage of being useless under water, consequently entirely incapacitated when the boat has sunk to the bottom as a result of an accident, when the necessity of emptying the tanks is most urgent and imperative. The inability to utilise these low-pressure air-compressors when the boat is submerged is due to the fact that they have no source from which to draw their supply of air and would be obliged to use the air in the boat for this purpose, resulting very soon in a partial vacuum that the crew would not be able to stand. In the case of an emergency, the German boats are therefore entirely dependent upon their supply of compressed air or the release of their safety keel to bring the vessel safely to the surface.

The radius of action or distance that a submarine can travel on the surface without refueling is a very important military consideration. In this connection one need only refer to vessels fitted with Diesel engines which burn

heavy oil as fuel. It has often been stated in the press that modern submarines have a radius of action of 6,000 to 8,000 miles without re-fueling. That statement is true, but it has to be qualified, not once, but twice. One is likely to assume that a submarine is capable of maintaining a maximum speed for that distance. That is, however, far from being the case. Every submarine is fitted with fuel storage tanks which under any and all circumstances are used for the purpose of carrying fuel only. In order to increase what might be called the legitimate radius of action, a practice has been introduced in recent years of fitting fuel piping to some of the water ballast tanks in such a way that those tanks, if desired, could be utilised as reserve fuel tanks, of course at the expense of the reserve buoyancy and seaworthiness. It is somewhat comparable to the practice of piling coal in bags on the deck of a destroyer to increase her steaming radius beyond what would be possible with only the coal bunkers filled. By adopting the expedient of filling part of the ballast tanks with fuel, and by running at a speed considerably less than the maximum speed, probably not more than 11 to 12 knots,

a radius of action of 6,000 to 8,000 miles without re-fueling can be attained. Of course the lubricating oil tanks must be of sufficient size to correspond with the extreme radius of action, a fact that in some earlier designs now in service has been flagrantly overlooked. It must also be borne in mind that when carrying this extra quantity of fuel in the ballast tank, the seaworthiness, free board and stability are all impaired to not an inconsiderable extent. A large submarine may have a surface speed of 18 to 20 knots, but at that speed the radius of action would invariably be found to be less than 1,000 miles, so great is the effect of speed upon resistance, and consequently upon power required for propulsion. To reduce the power sufficiently to attain a radius of action of 6,000 to 8,000 miles, the speed must be reduced to 11 or 12 knots, and in some cases even less. The radius of action at what is called the "cruising" or "economical" speed of 11 to 12 knots is generally computed by measuring the fuel consumption during a run of a few hours, thereby obtaining a rate of consumption per mile from which the radius of action can be determined. For purposes of practical navigation, however,

the figure so obtained has to be materially reduced owing to the frequent re-charging of the battery that is necessary, for which purpose the Diesel engine must be called upon to supply the power for driving one of the electric motors as a generator. The more frequently the battery is used for submerged running, the greater will be the reduction in the practical radius of action.

Many people are interested in the cost of a submarine, so a book of this kind would hardly be complete without some allusion to it. With the prices of all commodities so unstable as at the present moment, it is exceedingly difficult to state any definite figures under conditions continually changing and entirely lacking in permanency. Before the war, the average cost of a submarine was approximately $1,200 per ton of displacement on the surface. The surface displacement is the only fair measure of comparative value as it represents the actual weight of metal and material in the boat, whereas the submerged displacement includes a large quantity of water which may be more or less, depending upon the type. Since the outbreak of the war, the price of labor and material

has so increased that the present cost of a submarine is probably 60% higher than it was in 1914, and the rate at which the acceleration of prices is proceeding, may considerably modify that figure before this volume goes to press.

## CHAPTER VIII

### Submarine Antidotes

The methods of defence against submarine attack may be resolved into three separate categories: the first two positive methods being the destruction of their bases of operation or places of construction, and the destruction of the submarines themselves to prevent their activities. The third method of defence, which is somewhat negative in its nature, is to protect vessels as much as possible against torpedo attack either by constructional alterations or superior speed. The proposed construction of a vast number, either of wooden or steel ships, in the expectation that the number of submarines will not be great enough to find and sink them all and that a certain percentage will therefore get through safely, while it may serve the purpose and mitigate the disastrous effects of their ravages, cannot possibly be considered a satisfactory method of coping with or counteracting the sub-

marine. The passive defence of harbours or confined waters by means of nets and mines only constitutes a defence of the ships in these harbours as long as they remain in port, so that method likewise constitutes no defence of merchant shipping on the high-seas.

The first method mentioned, the destruction of their places of construction, varies in accordance with the circumstances of each individual case and hardly comes within the scope of this book. Although several bombardments of Zeebrugge, both from the air and from ships, have been undertaken and a few aeroplane raids have been made against the ship yards in western Germany where a number of these vessels are under construction, the experience of this present war conclusively proves that even with vastly superior naval power, the prevention of submarine activity by attempted destruction of the places where they are built, is exceedingly difficult. The most hopeful method would seem to be the destruction of the submarine itself, and this is also an exceedingly difficult matter. It will always be possible, if the circumstances are favourable, to so protect certain confined areas of water of vital importance

by means of nets and mines that the penetration of a submarine through the defences is highly improbable, but such circumstances are peculiar to certain localities and in dealing with the operations of fleet submarines on the high-seas this method is of no use whatsoever. The difficulty lies in the invisibility of the submarine and its practical immunity from counterattack by its intended victim. In the early stages of the war, the only type of vessel to achieve much success in hunting submarines was the torpedo boat destroyer. With her vastly superior speed and excellent manœuvring qualities, any submarine lying on the surface engaged in the operation of charging her batteries was in serious danger of being sunk either through ramming or by gun fire, especially when experience indicated the advisability of fitting sharp steel rams to the bows of a destroyer. Generally speaking, the destroyer is content to resort to gun fire, as ramming always involves the risk of running down a dummy periscope with a contact mine attached, to the serious damage of the destroyer.

Recently the destroyer flotillas have been augmented by swarms of picket boats which

scour the surface of the sea night and day looking for any submarine that may have come to the surface to refresh the air or re-charge the batteries. The picket boats in the English Navy are about 80 feet in length, while those under construction for the American Navy have a length of 110 feet. These vessels have a speed of about 25 knots and are of very shallow draft to give them immunity against torpedo attack. They are equipped with a small calibre rapid-fire gun mounted near the bow, and a powerful searchlight. As they are entirely unsuited for ramming, their only chance of destroying a submarine lies in penetrating the hull with a shell. Their comparatively small size, however, makes them a very poor gun platform, especially in circumstances where very accurate shooting is essential to success, and this same handicap of size frequently prevents their venturing outside the harbour at all in rough weather. Any one at all familiar with the Channel and the North Sea will appreciate the frequency with which rough weather may be expected, and will be the more able to appreciate the seriousness of this limitation of the sphere of usefulness of these picket boats.

The chance of destroying the periscopes by gun fire is infinitesimally small and, if accomplished at all, must be considered more luck than skill. If it so happened that both periscopes were destroyed by gun fire, the submarine would of course be obliged to seek safety in retreat and would probably navigate some considerable distance submerged to elude pursuit and would then sink to the bottom, or if too deep would submerge statically to await cover of darkness before commencing the homeward journey on the surface under the Diesel engines. Some years ago during the manœuvres of the Austrian fleet, in which the attacking force was endeavouring to penetrate the defences of the naval harbour of Pola, the Admiral in command of the defending forces stationed his submarines in suitable positions to intercept the battleships of the attacking fleet. The commander of the attacking forces was, of course, aware of the presence of these submarines, but had no knowledge of their position. Unknown to the other side, he enlisted the services of a number of small high-speed pleasure launches which were sent forth with instructions to search for the enemy submarines. In most in-

stances the submarines had the better of the encounter and several of the attacking ships were torpedoed. In one instance, however, one of these launches, equipped with a long-handled brush and a pot of black paint, slipped up unostentatiously behind a defending submarine and, coming abreast of the exposed periscopes, with one sweep of the brush, literally blackened the eyes of its opponent so that he was totally blinded. The commander of the submarine was entirely at a loss to understand what had happened and dived deeper in an effort to wash off the upper lenses of the periscopes, but all to no purpose. Disconcerted by the uncertainty of the situation, he came to the surface to make an investigation and found himself under the guns of one of the attacking battleships. The submarine was, of course, immediately ruled hors de combat by the umpire. It is not very likely, however, that this successful experiment could be repeated very frequently under conditions of actual warfare.

A shot through the conning-tower, or, for that matter, the knocking off of the entire tower, while it would temporarily incapacitate the submarine and require her return for repairs,

would by no means accomplish her destruction. In fact, the lower part of the conning-tower is specifically provided with a special joint of less strength than the connection of the conning-tower to the hull, for the precise purpose of permitting the conning-tower to be shot away without rupturing the hull connection.

As has already been explained, the periscopes at the lower end are fitted with a thick glass plate which effectually prevents the ingress of water into the boat, even where the upper portion is entirely shot away. In the same way, the entrance hatch into the conning-tower from the body of the boat is provided with a water-tight cover which is closed when the vessel is submerged, so that the loss of the conning-tower in no way impairs the navigating qualities of the boat. In fact, it is very difficult indeed to determine with any degree of accuracy when a submarine has actually been destroyed either by ramming or gun fire. There are cases on record in which English destroyers have charged full speed over a German submarine and the force of the impact has not only been felt on the destroyer, but the damage done to her bows has testified sufficiently to the vio-

lence of the collision. In this case one would certainly be justified in assuming that the submarine has been disposed of for good and all, were it not for the fact that it has been established beyond the question of a doubt that these same vessels have in certain cases returned safely to harbour. This is undoubtedly due to the protection afforded by the non-watertight super-structure running along the entire length of the top of the vessel, and the non-watertight wave breaker or fair-water built around the conning-tower. The collision with the upper works of a submarine would, of course, buckle the plating of the superstructure and possibly carry away the wave breaker and conning-tower, without, however, entailing the loss of the submarine. Even the large "spots of oil" so often quoted in the public press as convincing proof that a submarine has been destroyed is misleading. All of the German boats have fuel oil tanks in the superstructure. The rupture of one of these tanks might permit a large quantity of this "tell-tale oil" to float to the surface, but this fact need not necessarily indicate anything more than that the submarine has lost part of her fuel supply. In the recent case of

Dutch Submarine Running Submerged, Both Periscopes Exposed, Off the Mouth of River Scheldt

the Mongolia, in which the conning-tower was struck squarely by a shell and the destruction of the submarine was at first not doubted, the usual "tell-tale spots of oil" furnished its full quota of evidence. Later on it was definitely and officially established that despite the loss of the conning-tower and the spots of oil, the submarine had not been destroyed. All of the details of this incident are probably true as first narrated, even to the spots of oil, for it is a well-known fact that a shell in exploding on or near the surface of the water, always leaves a so-called slick or oily patch on the surface which in target practice actually serves to indicate where the shell has struck. All of which merely proves that despite shattered periscopes, smashed conning-towers, patches of oil and "large bubbles of air rising to the surface," the destruction of a submarine is a very difficult matter, and to determine whether or not it has been destroyed is equally difficult. One reads in the papers that the submarine "disappeared immediately after the shell exploded." Naturally, she disappears. If a submarine finds herself exposed to hostile gun fire at short range and in such a position that her torpedo

tubes cannot be brought to bear upon the attacking vessel, it is most urgently necessary that she should disappear, but it seems curious that that fact is accepted as conclusive proof that the submarine is lost. She simply resorts to submergence as the simplest and quickest method of escaping from a difficult situation.

The principal difficulty in destroying submarines is the difficulty of locating them. Much has been heard of the possibility of locating a submerged submarine from an aeroplane or airship. Many experiments along this line have been conducted in various countries and sensational articles have appeared from time to time in the press that the sun of the submarine had set with the advent of the aeroplane scout. The successful exploits of German submarines have effectually disposed of the idea that aeroplanes are an efficient defence against them. Whatever success the Allies may have had in destroying enemy submarines, it may safely be said that very little of it has been due to aeroplanes. This is, of course, entirely apart from the question of aeroplanes detecting submarines *on the surface* while charging their batteries or air flasks, and attacking them in this comparatively

helpless position with bombs or torpedoes. Various experiments conducted by different powers have amply indicated that the detection of a submerged submarine from an aeroplane was only possible under ideal conditions of wind and weather and only in those parts of the world where water of great clarity was to be found, as in the Mediterranean. Even under these conditions, a few light clouds in the sky were found to be most distracting, for their reflection on the surface of the sea gave the observer the impression that the sea was alive with submarines, and made it practically impossible to discriminate between the real submarine and the cloud reflection.

In the waters surrounding the British Isles, which are nearly always rough and without the least degree of transparency, where, moreover, the sky is heavily clouded and overcast, the futility of this method of detection is apparent. Even if perchance a submarine be detected on the surface, the chance of successfully bombing it from any considerable height is not very brilliant, and a certain respectful altitude must be maintained in view of the anti-aircraft gun with which the submarine is probably provided. Not

long before the war broke out an exhaustive series of experiments was made, in which the outline of the deck of a battleship was chalked out in a large open field, and the especially vulnerable spots, such as the tops of the funnels, represented bull's-eyes. A squadron of aeroplanes was provided to attack this ship, and the comfortable assumption was made that the ship was either not supplied with anti-aircraft guns or that the marksmanship was so poor that a hit was considered highly improbable, for the rules of the game permitted the aeroplanes to descend within 500 yards of the object of their attack. The result of these experiments was most comforting to the deck personnel of the battleship, for 90% of the bombs dropped failed to hit the deck at all and landed in the adjoining field, which corresponded to the sea. Of those that struck the deck, several landed near the edge, and not one entered the funnels. When one considers that the superficial exposed area of even a large submarine is about one-eighth of the deck area of a battleship, that the aeroplane would be taking a very serious risk to descend to within 500 yards of a vessel supplied with anti-aircraft guns, and that a submarine, even

when lying on the surface charging batteries, can disappear within three minutes, it would seem that the odds are much in favour of the submarine, even in this contingency.

A great many other expedients to effect the destruction of submarines have been employed, such as the mechanical explosion of mines in the water in the vicinity of a supposed submarine and sweeping for submarines lying at rest at the bottom of the sea, in the same way as trawlers sweep for mines, but no single method has yet been devised that may be considered a sovereign antidote for submarines.

It has frequently been suggested that submarines might be employed to hunt submarines. As the chief immunity from attack lies in its invisibility, it is difficult to understand how two submarines, enjoying reciprocally and mutually the same invisibility, will ever find each other except by chance, unless one of them is lying on the surface. This happened on one occasion in the present war, in which an Italian submarine was discovered on the surface by an Austrian submarine and sunk by a torpedo. When the submarine is on the surface, however, she loses for the time being her immunity from attack

and becomes to all intents and purposes a surface vessel. If submarines were employed systematically to search for submarines, the limitation of their submerged radius of action would necessitate part of the time being spent on the surface. The probability is, therefore, that the two submarines would sight each other at about the same moment, and the submarine wishing to escape always has the option of disappearing.

The third method of passive defence against submarines applied to certain localities and effected by means of wire nets to which contact mines are sometimes attached, is undoubtedly very effective, but the purpose it serves is very limited and is only effective in destroying submarines if they venture into it.

The possibility of effectually protecting vessels, either naval or mercantile, against torpedo attack is very doubtful. Constructional alterations may be attempted, which may retard the sinking of a vessel so attacked, but if this expedient proved so successful that the sinking of the vessel became questionable, it would undoubtedly be met by the use of more powerful torpedoes by submarines. In fact, torpedoes of

21-inch calibre to supersede the usual 18-inch torpedo have already been introduced in the more modern boats, although the present war has hardly indicated any necessity for them except in the case of the very latest types of battleships which are minutely sub-divided into watertight compartments. Even in that case, a second torpedo of the regulation 18-inch size would undoubtedly be just as effective. The German Government has already taken advantage of the ability of the submarine to approach within very close range of the intended victim by supplying even the earlier submarines with special 18-inch torpedoes in which the air chamber has been reduced in size, to dispense with the superfluous range, and the explosive charge has been correspondingly increased to enhance its destructiveness. Wire nets suspended around the sides of a vessel form a very dubious protection even when the ship is at anchor, in view of the efficient net cutters with which all torpedoes are provided, and the increased resistance that would be caused by dragging such a net through the water makes its use entirely inadmissible when the vessel is under way. In the merchant ship, as in the case of

the naval vessel, the most reliable protection against submarine attack is undoubtedly afforded by superior speed. In most cases it will be necessary to maintain maximum speed continuously, as the precise moment when a submarine attack can be expected could hardly be anticipated.

A great many people are already aware of the fact that a submarine in attacking a ship without warning discharges its torpedo without exposing any portion of the hull above the surface. That being the case, these same people are sometimes at a loss to understand what is accomplished by arming a merchantman as a defence against submarine attack. The great majority of merchant ships have a surface speed inferior to the surface speed of a submarine, and in most cases where unarmed merchantmen have been sunk by submarines, it has been the result of a pursuit in which the superior speed of the submarine has enabled it to overhaul the merchant ship and sink it either by gunfire or by placing a bomb on board with a clockwork mechanism attached. If a merchant ship is armed, however, the submarine is compelled to seek the protection and immunity

from gun fire afforded by submergence, but at the same time sacrifices the advantage of superior surface speed. Being obliged to depend upon the storage battery with its limited capacity for propulsion, the submarine is no longer in a position to overhaul the fleeing merchantman, and its victims are limited to those ships that unwittingly come within torpedo range. Moreover, the submarine is obliged to resort to the expensive torpedo, of which only eight to a dozen are carried on board, instead of being able to use a gun or effect her purpose with a bomb costing only a few dollars and of which perhaps a hundred may be carried. In many cases where the armed trawler is the object of attack, the question must arise in the mind of the submarine commander, whether the military and intrinsic value of his victim is worth the price of a torpedo.

It has been suggested that the construction and employment of large commercial submarines similar to the *Deutschland,* to ply between America, France and England, would entirely neutralise and nullify the blockade that Germany in endeavouring to establish around the British and French coasts. Quite apart from

the economic impracticability of building the necessary number of these vessels to carry even a fractional part of the tonnage that has to be transported, a brief analysis will demonstrate their futility for this purpose. If such vessels were built of about the same dimensions as the *Deutschland*, their cargo carrying capacity would be limited to about 200 tons each, and as they have to contend with the same difficulties as any other submarine in materially increasing the power of the Diesel engines, a practical limit to their displacement and consequently to their cargo carrying capacity is soon reached. One can readily imagine that an incredible number of these vessels would be required to make any impression at all, but in considering their feasibility for this purpose, let us waive all these practical considerations and assume that a fleet of sufficient size to handle the enormous volume of traffic is already in existence. Before reaching a British port, several hundred miles of war zone have to be traversed. As a German submarine may be encountered in any part of this war zone, this entire distance must be covered under water. In fact, to derive any benefit at all from the fact that they are capable

of submergence, they must run submerged; otherwise they are in obviously no better position than any other merchant ship sailing for a British port. It has already been shown that the maximum submerged endurance of a naval submarine is 20 hours at a speed of 5 knots, and the submerged endurance of one of these commercial submarines would probably be less because the submerged endurance, along with many other qualities, would be sacrificed for cargo carrying capacity. If a war zone of 300 miles in width has to be traversed entirely submerged, it would mean that 20 hours would be occupied in covering the first 100 miles. The batteries would then be exhausted and the vessel would have to come to the surface for a period of five hours to re-charge the batteries. A second run of 100 miles would then be possible, after which the batteries would again have to be re-charged. In this way, in stages of 100 miles, at a speed of 5 knots, the vessel would endeavour to cross the war zone in safety and reach port. Those who are even slightly familiar with the waters around the British Isles know that there are places in which the speed of the current is nearly 5 knots. If the

current in any particular place happened to be adverse, the submarine would remain substantially in the same spot without making any headway against it. One may say that there are places in which the war zone is less than 300 miles in width, but it must not be forgotten that the war zone is an arbitrary creation of the German imagination, and if the Germans discovered that the Allies were eluding their submarine blockade with a large measure of success by running through the war zone submerged, it is merely a matter of an Imperial edict to extend the war zone to a point 500 or 1,000 miles, if necessary, off the British coast, and German submarines would be stationed further out in the Atlantic to take care of the venturesome commercial submarines that deferred their submergence until too late. The practical result would be that eventually the only safe course for the commercial submarine would be to submerge in New York Harbour and come up again in Liverpool, which any one will admit to be an utter impossibility.

## CHAPTER IX

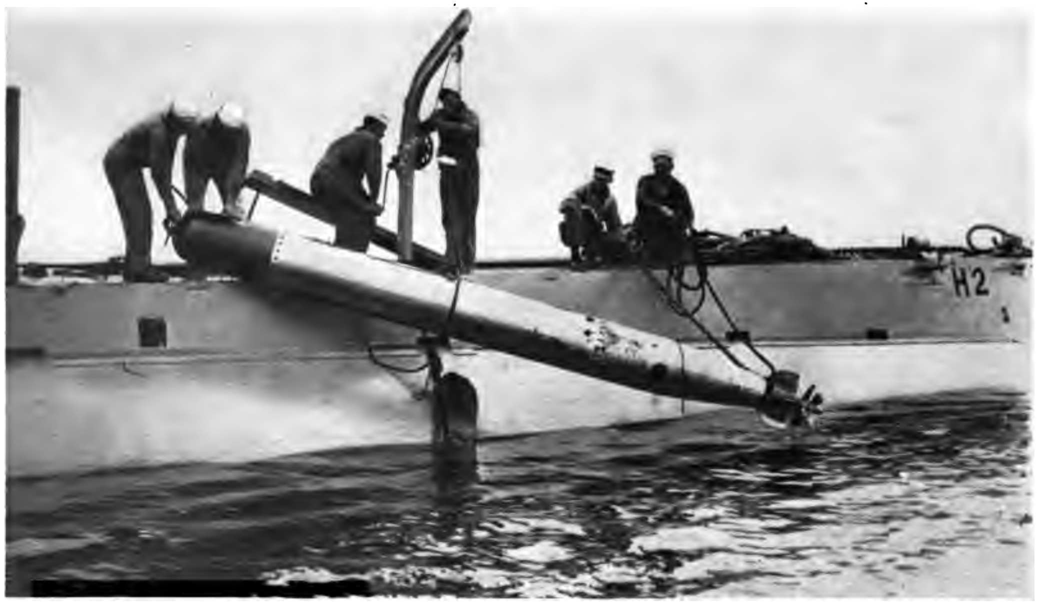
### TORPEDOES

THE original idea from which the present automobile torpedo has been evolved was conceived in about the year 1865 by a certain Captain Luppis in the Austrian Navy. As his idea was purely theoretical and his knowledge of practical mechanics was very rudimentary, he consulted Mr. Robert Whitehead, an Englishman, who owned and managed a small machine shop in Trieste. Working upon the idea conceived by Captain Luppis, Mr Whitehead built his first torpedo, a model of which is to be seen in the present works of the Whitehead Company now situated in Fiume, Hungary, on the shores of the Adriatic. This torpedo was crudely constructed of iron plate and had a diameter amidships of about 12 inches and a length of 8 feet and was tapered to a sharp point at both ends. The nose of this device carried an explosive charge of about 20 lbs. of gun

cotton; the middle portion, which was about half of the total length, formed the air chamber in which the compressed air for propelling it was stored, and the after-end or tail containing the engine by which it was propelled and the gear for steering it in the horizontal and vertical planes. It had a speed of only 6 knots at a very short range, and its steering, both in the horizontal and in the vertical plane, was exceedingly erratic, but in principle it embodied the essentials of the torpedo of to-day.

By a gradual process of development combined with the invention of several ingenious devices to increase its accuracy, the modern torpedo has been evolved. Although there are several makes now on the market, the principal characteristics are so similar that a description of the Whitehead torpedo will practically suit them all.

The type most commonly in use has a diameter of 18 inches or 45 centimetres, and a length of about 17 feet. The torpedo is divided longitudinally into three sections, as was the case in the first torpedo built. The first section in the nose of the torpedo contains the explosive charge of about 175 lbs. of gun cotton. In the

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LOADING A TORPEDO THROUGH A SPECIAL HATCH

extreme nose of the torpedo is situated a firing pin which, upon contact with any solid object, detonates a small charge of fulminate of mercury, which in turn explodes the main charge of gun cotton. In order to prevent premature explosion and the possibility of injury to the ship from which the torpedo is fired, the firing pin at its outer end is fitted with a miniature propeller that is caused to revolve by the passage of the torpedo through the water. Until the torpedo has traversed a distance of about 150 feet, the firing pin is locked and the explosive charge cannot be detonated. The rotation of the miniature propeller during the passage of the torpedo through the water eventually releases the locking gear on the firing pin, so that after the torpedo has travelled the prescribed distance of 150 feet it will explode upon contact with any solid object. For naval manœuvres and torpedo practice, a special collapsible head, known as the exercise head in contradistinction to the war head, is fitted. The exercise head has the exact shape and size of the war head, and is filled with water to represent the weight of the explosive charge. When the torpedo makes a hit, the exercise head merely

crumples up and has to be replaced with a new one, without damaging in any way the rest of the torpedo. The length of the head measured from the nose to the beginning of the air chamber is about 3 feet.

The next section is the air chamber, which contains compressed air at a pressure of 2,150 lbs. per square inch to supply the energy for propelling the torpedo. This chamber has a length of about one-half of the total length of the torpedo and is made usually of very high grade steel about 3/8 of an inch in thickness, although it is occasionally made of bronze. One interesting fact in connection with the air vessel is that when it is fully charged with air, the pressure is so great that the walls are distended and an accurate measurement of the torpedo made with the air vessel fully charged will disclose the fact that it is about 1½ millimetres larger in diameter than when it is empty. In the air chamber there is no machinery or mechanism whatsoever.

This is all concentrated in the stern section or tail of the torpedo. The tail contains the four-cylinder engine which operates the propellers, the cylinders of the engine being arranged

radially at right angles to each other around the central shafts. There are two propellers, one immediately behind the other and rotating in opposite directions, one propeller being driven by an inner shaft, the other propeller being driven by a hollow shaft around and concentric with the inner shaft. In fact, the inner shaft is likewise hollow and is utilised as an exhaust pipe for the compressed air after it has passed through the engine. This same compartment contains the automatic steering gear, depth gear and air heating device. Before the introduction of the so-called Obry gear, also the conception of an Austrian naval officer named Obry, the steering of a torpedo was very erratic, and the utmost exactitude in aiming, combined with firing at close range, did not necessarily insure a hit. The Obry gear, which is the adaptation of the gyroscopic principle to the steering gear, has practically eliminated the element of uncertainty formerly due to erratic steering. The principle of the gyroscope as applied to the steering gear is similar to that of a fly wheel rotating at high velocity in a given plane. It is well known that under these circumstances any external effort to alter the plane of rota-

tion is violently resisted by the action of the spinning fly wheel. This principle is made use of in the steering gear of the torpedo by fitting a small fly wheel, which is made to rotate at very high speed either by the action of a coil spring or, in more recent torpedoes, by a blast of air at high pressure from the air flask at a moment just prior to the firing of the torpedo when the torpedo tube is pointed accurately in the direction the torpedo is intended to follow after it has been discharged. Any tendency of the torpedo after discharge to divert from its true course at once communicates a movement to the steering gear through the action of the gyroscope, which shifts the steering rudders at the tail of the torpedo and immediately counteracts the incipient divergence. Advantage is sometimes taken of this faculty of the gyroscope to effect what is known as broadside firing from the bow tubes of a submarine. The gyroscope is set to act at right angles to the line of the torpedo tube, so that after discharge the torpedo makes a right angle turn and pursues the same course as if it had been fired from a broadside tube. This method has not proven entirely satisfactory, however, as the exact moment at

which the torpedo should turn and the radius of the turn cannot be determined with sufficient accuracy, and both of these elements considerably affect the probability of a hit being made. A number of people seem to be under the misapprehension that a torpedo travels along the surface throughout its entire course. To those who are under this impression, the function of the depth gear will be interesting and novel. The depth gear is a very reliable automatic device which controls the depth below the surface at which a torpedo shall run, and this adjustment is made by simply turning a dial, as one would set an alarm clock, before the torpedo is loaded into the tube. The torpedo can be set to run at any depth below the surface up to 20 feet. In adjusting the depth at which the torpedo is to run, the nature of the target must be taken into account. In firing at a battleship, one wishes to be sure to strike the ship well below the armour belt, so the depth gear is set for 15 feet. If a torpedo adjusted to run at this depth were fired at a destroyer, it would pass harmlessly under the keel, so in the case of a destroyer the depth gear must be set to 5 feet, or thereabouts. It is never under any

circumstances set to run upon the surface. In torpedo practice, the torpedo floats to the surface after the air supply is exhausted and the run is finished because of the slight amount of buoyancy, and it is desirable that it should do so in order that it may be recovered. Under war conditions, however, a sinking gear which is required by international law is put into operation, by means of which the torpedo is caused to sink after a run in which it has missed the target. This precaution is equally desirable as a torpedo floating around on the surface with a war head likely to go off on the least contact, is a menace to friend and foe alike, and the bottom of the sea is the safest place for it. If the torpedo finds its mark, the terrific concussion caused by the explosion of the war head blows a huge hole in the side of the ship, and at the same time shatters the torpedo into a thousand fragments.

In daylight one can follow the course of the submerged torpedo by the track of air bubbles that rise to the surface in its wake. This fact is not of much value to those on board a ship under attack as the speed of the torpedo is so great that there is rarely time to get out of the

way after the track of the torpedo has been observed. Moreover, the position of the torpedo is nearly 100 yards in advance of the track of air bubbles. This advance represents the distance the torpedo has covered in the time it takes the air bubbles to rise to the surface.

All modern torpedoes are fitted with some means of heating the air after it leaves the air vessel and before it enters the engine. Petroleum is usually employed for this purpose. By heating the air, the volume is greatly increased, whereby the range and speed of the torpedo are increased proportionately. Eighteen-inch torpedoes fitted with a heater have a range of about 6,000 yards and have an average speed of 30 knots, or a speed of 38 knots at a short range of 1,000 yards. It will, of course, be understood that in setting the torpedo to run at the higher speed, the consumption of air is much more rapid, consequently the range is reduced; but in conjunction with its use on submarines and the ability to approach within close torpedo range, the higher speed is a much more important element in making a hit than superfluous range. The 21-inch or 53 centimetre torpedo that has made its appearance within the

last five years, has a length of about 21 feet and more than double the explosive charge of the 18-inch torpedo. It has an effective range of 10,000 yards at a speed of 35 knots, and a maximum speed of 45 knots at close range. The cost of an 18-inch torpedo before the war was about $3,300, and the large torpedo $6,000. Under the abnormal conditions existing at the present time, these prices have become about $5,500 and $9,000, respectively.

As long as the mechanism is in good working order, which must be verified at frequent intervals, a modern torpedo is very reliable, but if anything goes wrong with the control gear, its antics may be very diverting, and sometimes dangerous. Under these conditions, if anything interferes with the proper functioning of the depth gear, the torpedo may dive at once to the bottom and bury itself completely in the mud, or it may shoot bodily out of the water like a porpoise or flying fish. It sometimes happens that both the depth gear and steering gear will get out of order at the same time, in which case the torpedo would perform some of the most astonishing gyrations, darting off at all kinds of unexpected angles, in some cases even turn-



A Spent Torpedo

ing around and torpedoing the ship from which it was fired. With a knowledge of these possibilities, the solicitude with which the mechanism is cared for in war time may well be understood.

The Whitehead torpedo has now been adopted by practically all the navies in the world. Besides those manufactured in the Whitehead works in Fiume for all of the smaller countries, England and France are supplied by the branches of the Whitehead works in those countries. The majority of the torpedoes for the United States Navy are manufactured by the E. W. Bliss Co. under a license agreement with Whitehead, although a certain number are manufactured by the Government. Germany is the only great power that does not use Whitehead torpedoes. The torpedoes used by Germany are of the Schwartzkopf type, which is the same thing by another name. The only one of the smaller powers to manufacture its own torpedoes is Denmark. Some years ago the Danish Government bought the license outright to manufacture Whitehead torpedoes, since which time they have been building them in the Royal Dock Yard with conspicuous success. During the

present war Germany has developed a smaller torpedo, about 14 inches in diameter, costing less than the 18-inch type and of such dimensions that a considerably greater number could be carried by a submarine. This departure was due to a realisation of the fact that an 18-inch torpedo expended in sinking a merchantman frequently represents a great deal of energy wasted.

The principal if not the only offensive weapon with which the modern submarine is provided, is the torpedo. During the present war, however, the sowing of mines indiscriminately in the North Sea and in the waters surrounding the British Isles combined with the difficulty of doing this in the usual and conventional way by dropping the mines overboard from the stern of a mine-laying vessel, has caused the German Government to take up the construction of special mine-laying submarines. The mine-laying submarines have no armament other than a small rapid-fire gun, so that if discovered at their work their only safety lies in submergence. The mine-laying apparatus consists of two perpendicular tubes or tunnels, one forward of the conning-tower, the other abaft the conning-

tower, which pass through the hull from the top of the superstructure deck to the keel. These tunnels are open top and bottom and are therefore in communication with the sea. The diameter is about 30 inches to suit the mines, and the mines are loaded from the upper end, a mechanism at the lower end preventing their dropping out. Each tunnel contains about 6 mines. The operation of these submarine mine layers is exceedingly simple. Having arrived at the spot where it is desired to sow the mines, a releasing mechanism operated from inside the boat permits each mine with its anchor to drop out of the lower end of the tunnel. With the exception of the lack of armament and the special apparatus for laying mines, the vessel is in all other respects like an ordinary submarine. Those that have been built hitherto have not exceeded 500 tons in displacement.

## CHAPTER X

### The Sphere of the Submarine in Naval Policy

Whatever may be the consensus of opinion among naval experts regarding the relative value of submarines versus dreadnoughts, there is practically unanimity of opinion in all countries that the submarine must form a definite part in the scheme of naval policy. The importance attached to them and to the rôle they are expected to play necessarily varies among different powers in so far as their naval policies differ to suit the requirements and conditions of the particular power. Whatever one's opinion may be as to the legality or illegality of employing submarines to attack and sink merchant vessels without warning, the indispensable function that these vessels fulfil is undisputed. It is generally considered that in any case, for a long time to come, they will not entirely replace capital ships except in such countries as Holland, Denmark, Norway and

Sweden, which, for financial reasons, if for nothing else, are unable to maintain a first-class battle fleet and whose naval policy must therefore necessarily be exclusively defensive.

As indicated in a previous chapter, there is a tendency to divide submarines into two general classes: the smaller class, as a rule not exceeding 500 tons' displacement, known as coastal submarines, being used for purposes of coast and harbour defence, operating in groups from a shore base. In view of their comparatively small size and the necessity for remaining in the proximity of the base to be defended, a considerable number of vessels of this type is considered necessary for the effective defence of a coast line, the number depending upon the length of coast to be protected and the number of harbours subject to attack. A rough approximation of the number required may be stated as one boat for every ten miles of coast line. The other and larger type of submarine required for offensive operations is just as essential for the power whose policy is defensive as for the power commanding the sea. These sea-going submarines, usually designated fleet submarines, are utilised for blockading the

enemy coast, raiding enemy shipping and accompanying the battle fleet, if there be such a thing. As they must keep the sea in any weather for long periods of time, it is essential that they be large, roomy and habitable, with ample free board and deck space for the crew in fine weather, and comfortable sleeping accommodation below. The necessity to accompany the battle fleet implies high surface speed of at least 18 knots, with the greatest practicable radius of action and sufficient stowage accommodation for food and provisions to keep the crew well supplied for a period of three to four weeks.

Paradoxical as it may seem, the last of the great powers to admit the desirability of or necessity for submarines was Germany, and that conclusion was only reached under the pressure of actual war, when it was manifest that the rest of her fleet was of practically no use. If one believes that the German Government has been preparing for many years in anticipation of the present war, it seems incredible in view of the completeness of her preparedness in all other respects that the submarine arm of the naval service was entirely

neglected and hopelessly discredited up to the day that war broke out. It was assuredly no oversight on the part of the German authorities, for in several conversations the author had with Admiral von Tirpitz in 1911 in regard to Germany's submarine policy the latter expressed emphatically as his opinion that he considered submarines to be in an experimental stage, of doubtful utility, and that the German Government was not at all convinced that they would form an essential or conspicuous part of their future naval programmes. This opinion, which undoubtedly incorporated the opinion of his principal subordinates, was not expressed with any purpose of misleading, for it was a well-known fact at the time to every one in the profession that Germany's position in the matter of submarines was that of a third-class power, and the author's conversation with him on the subject was due primarily to a desire on his part to bring about a change of attitude, if possible, and convince von Tirpitz of the necessity of building submarines. This effort was unsuccessful and that attitude was maintained until about a week after the outbreak of war. At that time Germany had about

25 submarines in commission and was building perhaps half a dozen more. They were all of the Krupp-Germania type, and von Tirpitz explained almost apologetically that they had built a few just to be able to form some conclusions regarding them based on their own experience. It was evident at that time, however, that no great thought or attention was being devoted to their development, nor were ideas from outside sought.

Any casual student of European politics during the last fifteen years knows that in every international complication that arose and threatened European peace Germany was always to be found on one side and England on the other side as potential antagonists. If Germany had foreseen every contingency and provided for it in advance, she must necessarily have regarded the participation of England as an adversary in the present conflict, or, in fact, in any conflict in which Germany was involved, as a possibility at least, even if a remote one, and she must also have foreseen that the participation of England would bring about the enforced inactivity of the German high-sea fleet. She could also have foreseen the situa-

tion that now prevails, i.e., the submarine branch of her naval service would be the only one that could deliver any effective blows against England. Under these circumstances, how is it possible to explain the utter failure of the German Government to comprehend, or, if they comprehended, to provide for the rôle that submarines are playing to-day? Is it possible the General Staff and the Reichs Marineamt refused to recognise the possibility of England's participation as even a remote contingency, and that no appropriate preparation was made to meet it? It would almost seem so, for when England definitely entered into the conflict against Germany steps were taken in feverish haste to lay down over sixty submarines at once, and that number has since been largely augmented. It is generally believed that the term "U-boat" frequently employed in reference to German submarines has some peculiar significance, that it is used to designate some particular type or group. This, however, is not the case. The prefix U is simply a convenient abbreviation of "Unterseeboot," the German translation of "submarine," and as such is employed by the German Admiralty to distinguish

torpedo boats and torpedo boat destroyers from submarines, all of which vessels are listed numerically and are without names. All of the German submarines, from the first to the last, are U-boats and one can only distinguish the group to which a boat belongs by familiarity with its numerical position on the list. It would be comparable to our use of the expression "S-boats" in discussing submarines. The term "U-boat" is also employed in Austria, where German is the official language of the Navy.

In the United States and England, however, letters of the alphabet, to distinguish various groups or types, are employed in conjunction with the service number of the individual boat.

In the subsequent discussion of the probable number of submarines now possessed by Germany it may be accepted as certain that the numbers observed give no clue to the total number of boats built. If, some day, the U-535 makes a raid on the Atlantic seaboard, we need not be alarmed by the inference that Germany must possess *at least* 535 submarines, for it is not to be supposed that we will be kept informed of the numerical strength of the Ger-

man submarine fleet by a consecutive numbering of the vessels built.

Under normal circumstances, working eight hours a day, it takes from 22 to 24 months to build a submarine, and this time is practically independent of the size of the submarine. The reason for this comparatively long time for building such a small vessel is to be found in the fact that the internal space is so cramped that the number of men who can be advantageously employed inside is quite limited, not being more than 20 to 30. In the first stages of construction, before the frames are erected and the vessel is plated, a larger force can be utilised, but as soon as the framework is erected and the plating in place the number of men must be reduced. Moreover, the limitations of space necessitate the installation of a large part of the machinery consecutively and not simultaneously, which is another factor that tends to protract construction.

The only method by which this time of construction can be substantially reduced is to employ three entirely separate shifts and work 24 hours a day. By this means, under the pressure

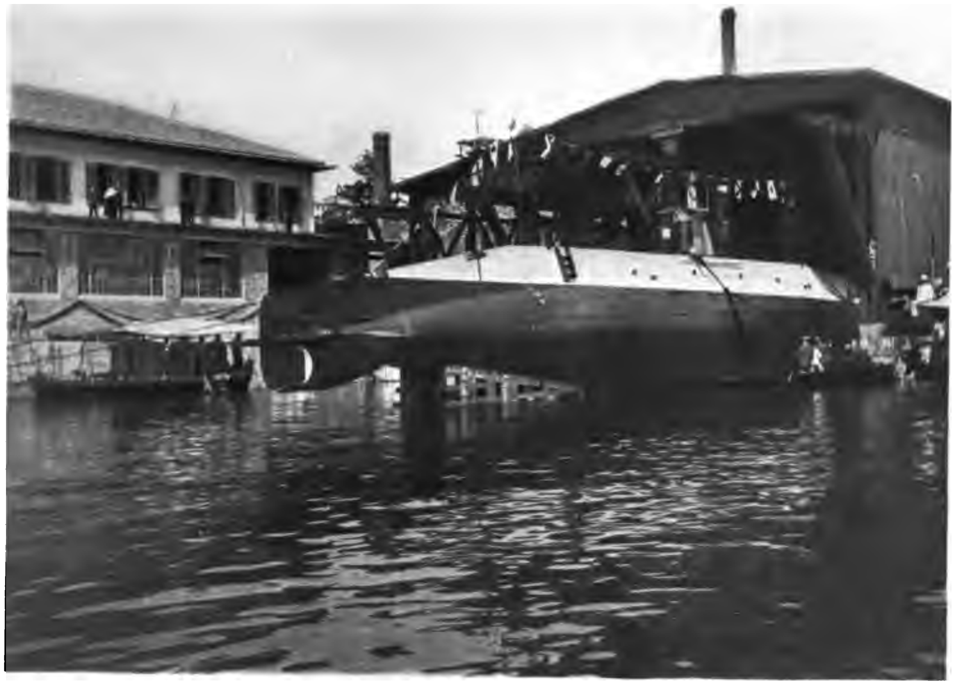
of war conditions and with Gověrnment assistance to insure the prompt delivery of all those parts of the machinery that must come from outside manufacturers, it is possible to complete one of these vessels in seven to eight months.

The question has often been asked, "If it takes seven to eight months to build one submarine, how long will it take to build ten under the same conditions?" There is no reason why it should take any longer to build ten submarines than to build one. It is purely a question of having the necessary facilities to build the larger number and the necessary number of men to work upon ten vessels simultaneously. Irresponsible statements in the press about "delivering submarines at the rate of two a week" have been so worded as to convey the entirely erroneous impression that the construction of the two vessels in question was completed within a week. There is nothing whatsoever to prevent submarines being delivered at the rate of two a week, or two a day, for that matter, provided the construction of them was commenced at least seven or eight months before the day on which they are de-

livered. Perhaps the phase of this question in regard to which the wildest misstatements have been made, and one which is naturally of vital interest to the general public in all the allied countries at this time, concerns the number of submarines that Germany possesses at the present moment and the number she is capable of building.

Estimates have appeared in print according to which Germany is credited with having over 700 submarines in her possession at the present time (May, 1917), and that 1,200 will be in commission by the end of the year. It can hardly be possible that such an estimate has been made by any person familiar with the shipbuilding facilities of Germany, even making all due allowance for abnormal expansion of these facilities to meet the necessities of the occasion. It has been stated that drydocks would even be utilised for the purpose of erecting them, as if the problem were primarily one of ground space. The entire shipbuilding capacity of Germany is very limited, compared with England, for instance, and the difficulty of finding highly trained and skilled shipbuilding labour such as is required for the intricate

work of constructing a submarine would militate heavily against any sudden increase in the tonnage that could be turned out. The manufacture of storage batteries and Diesel engines in sufficient numbers would also present serious difficulties, as special equipment and much experience and skill are required for work of this class. It is, of course, true that parts of Diesel engines could be manufactured in machine shops all over the country and shipped to centralised erecting shops to be assembled, and this practice has indeed been followed. Whether or not Diesel engines constructed in this way would run satisfactorily, is quite another question. It is notoriously a fact that some of the licensees of the principal continental Diesel engine manufacturers have constructed duplicate engines from exactly the same plans that have been unable to pass any of the naval requirements, whereas the identical engine manufactured by the original manufacturer had been at once successful. Taking into account all the shipbuilding facilities of Germany, both private and governmental, making the most liberal allowance for the maximum extension of these facilities under pressure of war, bearing in



Launch of an Austrian Submarine

mind at the same time the difficulty experienced in obtaining certain necessary machinery and appliances and in obtaining skilled labour, and deducting the number of submarines that have probably been lost or destroyed by the enemy, it does not seem possible that Germany has more than 200 submarines in commission at the present time. Of this number approximately two-thirds would be constantly available for duty, while the other one-third would be en route either to or from the various shore bases for the replenishment of supplies and for repairs.

In arriving at this conclusion the comparatively small number of submarines possessed by Germany at the outbreak of the war has, of course, been taken into consideration, and this opinion does not represent the judgment of the author alone but represents the consensus of opinion of several experts whom he has consulted, who were in a position to make independent estimates, the basis of which consisted, to a considerable extent, of actual knowledge and information.

To arrive at a fair or accurate estimate of the rate at which Germany can build subma-

rines in the future is somewhat more difficult. Assuming, however, that all yards in the country were utilised exclusively for this kind of work and that no mercantile shipbuilding or repairs to the battle fleet were undertaken, which, of course, is far from being the case, the probability is that not more than 100 submarines could be completed every six months.

The creation and maintenance of this extensive submarine fleet introduces a difficulty that is not to be underestimated: that of trained crews. In a vessel of this type, where one moment of inadvertent negligence or abstraction on the part of any member of the crew might be responsible for a fatal disaster involving the loss of the boat, the importance of a highly trained, intelligent and expert crew is paramount. To send out a submarine with a crew having the necessary degree of intelligence, but only indifferently trained, would be extremely hazardous, and in such circumstances the loss of a single boat becomes a vital matter. Without arguing this point any further, however, we may assume that Germany will find it possible to train a sufficient number of men to command as many boats as she can build. If

Germany had been willing to consider the entrance of England into the war as even a remote possibility and had safeguarded herself against that contingency by creating an extensive submarine fleet before the war broke out, and had immediately enforced a blockade of the British Isles with the same degree of ruthlessness as she has now adopted, and had not deferred matters until she was herself on the point of starvation, the international political and military situation would be very different from what it is to-day.

Great as has been the improvement in submarines, especially during the last ten years, it is nevertheless a fact that there is more room for further improvement in these vessels than in any other class of war vessel. Without doubt, the immediate impediment to a sweeping improvement in conditions both of submerged and surface navigation lies in the present necessity for a dual propulsion system. In navigating submerged, the entire weight of the main engines, amounting possibly to 8% of the total weight of the boat, and the entire space occupied by them, is utterly wasted as far as any advantage to the submerged qualities of the

boat is concerned. Conversely, when navigating on the surface, the weight of the batteries, amounting to about 16% of the total weight of the boat, and the space they occupy, together with the weight and space occupied by the main electric motors, contribute nothing to the military value of the boat. If the main battery were not required for submerged propulsion, a comparatively small storage battery and generator driven from the main shaft would be quite sufficient for all purposes of lighting and driving the auxiliary machinery. The greater part of 16% of the total weight would at once become available for increasing the speed of the boat, the radius of action or the armament, or apportioned among all three. If the engineering problems that now stand in the way of the Diesel engine being used under water were satisfactorily solved, not only would the surface speed, radius of action and armament benefit by the saving in weight effected, but in addition the utilisation of the Diesel engine for propulsion submerged would, in view of its much greater power, render a much higher submerged speed easily attainable. The elimination of the storage battery as an element in pro-

pulsion would obviate the necessity for frequent recharging, with the consequent frequent intervals of enforced inactivity during which the vessel must navigate on the surface in a vulnerable position. The radius of action submerged would also be very greatly increased, as fuel oil would supply the motive power instead of electrical energy, of which comparatively only a very small amount can be stored in the space available. Such an improvement as the substitution of a single system of propulsion instead of the dual system now in use would involve such radical and far-reaching improvements in every respect that it might fairly be said that it would revolutionise the art of submarine construction as at present understood.

Although it is very difficult to exactly predicate the changes that future development, and especially this development, will bring about, it does not seem likely that much of the economy in weight and space will be utilised for armouring the vessel above the water line, although a certain amount may be employed for fitting heavier guns than are now used. There may be an attempt made to armour the conning-

tower. This has, in fact, been attempted in earlier vessels, but the serious objection to armouring either the conning-tower or the exposed portion of the vessel is the ensuing loss in stability. In the design of an ordinary war vessel, reduction in stability due to the installation of heavier guns or other top weights is very easily offset by increasing the "form" stability. In fact, a vessel intended only for surface navigation has no stability other than form stability, and its increase is accomplished by making the vessel broader in relation to its depth. This expedient would suffice for a submarine also, as long as navigation was confined to the surface; but in navigating submerged the submarine loses all stability due to form, and in this condition the only stability she possesses is derived from the fact that, as in a pendulum, the centre of weight is below the centre of suspension. It would be exceedingly difficult to add any considerable weight to the upper part of the vessel either in the form of an armoured conning-tower or in armouring the exposed portion, without making it impossible to obtain sufficient stability submerged.

The general trend of development in the last

ten years has been in the direction of larger displacement. Vessels of recent design have four and five times the displacement of those that were constructed a decade ago. This tendency has undoubtedly been due to the fact that the earlier vessels were too small to enable satisfactory conditions of habitability to be secured, and were also deficient in seaworthiness in rough weather. It would seem unlikely that this tendency to larger displacement will continue during the next ten years—at least at the same rate. Vessels of 800 to 1,000 tons' displacement are palatial in their accommodation, compared to boats of 200 and 300 tons, so the limitations of habitability are no longer keenly felt, and unsatisfactory seaworthiness is a stigma which cannot apply to a vessel of 800 to 1,000 tons. There is, therefore, no longer the same impulsion to increase the size of the vessel; in fact, to the contrary, there are certain very good reasons which render any large increase in size at the present time undesirable. The larger vessel is inherently more unwieldy in submerged navigation and requires deeper water in which to navigate submerged with safety, and this unwieldiness increases

with the size. Moreover, any material increase in displacement involves an increase in the power of the Diesel engines, whereupon we are immediately confronted with another engineering difficulty. Efficient submarine Diesel engines of 150 to 200 h.p. per cylinder have been successfully constructed, but as soon as larger units are attempted difficulties multiply rapidly. Multiplicity of cylinders is undesirable because of the danger of break-down as the mechanism becomes more complicated and extensive, and unreliability is a deadly sin in a submarine engine. Furthermore, in contradistinction to the steam engine, in which the weight per h.p. decreases as the engine increases in size, the Diesel engine, with irritating perversity, increases in weight per h.p. as the size of the engine increases. In designing a submarine of greater displacement, therefore, it is not sufficient to increase the weight allotted to the engines in the same proportion as the displacement of the boat is increased; it must be increased in greater proportion, which of course implies that it must be increased at the expense of some other characteristic. When the problem of a single system of propulsion has been

solved, however, a certain part of the weight and space saved thereby will most certainly be devoted to increasing the speed and increasing the power plant. It is, of course, not to be supposed that the submarine will ever approach the destroyer in speed, or, for that matter, any of the ships constituting the battle fleet. The structure of vessels intended for surface navigation need be only of sufficient strength to withstand the stresses to which they are subjected in a seaway and the local stresses produced by firing the guns. These stresses are in no way comparable to the tremendous stresses caused by the pressure due to deep submergence which the hull of the submarine must be capable of withstanding, and to accomplish which a very large proportion of the total weight of the vessel must be devoted. Besides this important factor which operates to the disadvantage of the submarine, it must be borne in mind that although approximately ship-shape form is within the realm of possibility, it is by no means possible to construct a submarine on lines that are as well suited to high surface speed as those of a destroyer. While it is generally understood that more speed requires

more power, the extent to which this is the case is usually not realised. Though it is impossible to state any definite rule giving the ratio at which the power increases, corresponding to an increased speed, as this depends upon many factors that vary with the invidual boat, it may generally be stated that the power varies in proportion to the cube of the speed, and in some cases, especially at very high speeds, the variation in power will frequently exceed the cube of the speed, and sometimes even approaches the fourth power. To visualise this statement, a hypothetical case of the relative power required to propel a given boat at a speed of 10, 20 and 30 knots is appended hereunder:

| SPEED | CUBE OF SPEED | POWER REQUIRED VARIES AS: |
|---|---|---|
| 10 | 1,000 | 1 |
| 20 | 8,000 | 8 |
| 30 | 27,000 | 27 |

From a casual examination of these figures it will appear that to increase the speed from 10 to 20 knots, 8 times as much power is required, and to increase it to 30 knots, 27 times

as much power is required. If we assume that we are dealing with a modern submarine having a maximum surface speed of 20 knots, the virtue of running at a cruising or economical speed of 10 knots to increase the radius of action is at once apparent, for the power required is only one-eighth as much as is required at full speed. If we further assume that the vessel has a sufficient quantity of fuel oil to last for 50 hours at full speed, the radius of action at that speed would be 1,000 miles. As the power required for 10 knots is only one-eighth as much, the same quantity of fuel at a speed of 10 knots will last for 400 hours, which gives a radius of action of 4,000 miles at that speed, or four times as great as at full speed. This statement is subject to some qualification, as the consumption of fuel oil by the Diesel engine is not quite as economical at reduced speed, but it is nevertheless approximately correct and will clearly show the great advisability of running at reduced speed to obtain the maximum radius of action. If, on the other hand, the problem of a single system of propulsion were suddenly solved and an endeavour were made to increase the speed of the same boat

from 20 to 30 knots by utilising a portion of the weight saved by the elimination of the battery, the power of the engines to accomplish this result would have to be increased in the proportion of 8 to 27. In other words, nearly three and one-half times as much power will be required. This is based, moreover, on the assumption that at a speed of 30 knots the power varies as the cube of the speed. In practice this assumption would be found too favourable, and a power at least four times as great as that required for a speed of 20 knots would be necessary to insure 30 knots. As the weight of the main engines is approximately 8% of the total weight of the boat and the weight of the battery is 16% of the total weight of the boat, the total amount of weight available for other purposes by the elimination of the battery is only equal to twice the weight of the main engines. It will therefore be manifest that even were this saving in weight entirely devoted to increasing the power of the main engines, the attainment of a speed of 30 knots is impossible even without taking into consideration the fact that the weight of the engines per horse power increases as the power is increased. In all

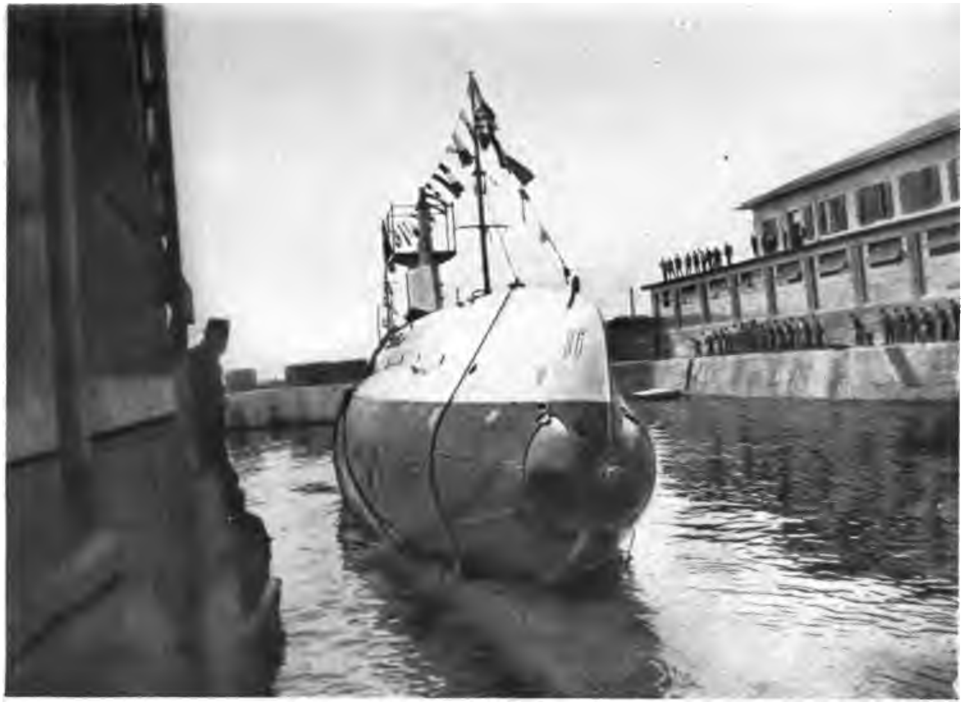
probability the solution of the problem of the single system of propulsion applied to a vessel of 20 knots surface speed now operating on the dual system, would enable the surface speed to be increased to 25 or 26 knots. A certain amount of weight would surely be devoted to armament and radius of action, and the apparatus that would permit the use of the Diesel engine submerged would also demand some consideration from the point of view of weight. Even if none of the saving in weight effected by the introduction of the single system of propulsion were devoted to increasing the surface speed, it would still be of inestimable value from the fact that the total power of the main engines could be utilised for submerged propulsion and a very necessary improvement in submerged speed and radius of action brought about.

Another inherent disadvantage under which the submarine labours in comparison with surface ships, is the necessity for setting apart about 25% of the entire cubic contents of the vessel as the space required for water ballast. The loss of this very large amount of space which, in the submerged condition, is filled with

water and must be treated as weight, permanently bars the possibility of a submarine ever being able to compete on equal terms with a surface vessel of like displacement.

In spite of the serious inherent disadvantages mentioned, it may be surprising to learn that in point of armament, radius of action and seaworthiness, a modern submarine already considerably surpasses any destroyer of equal size. By the term "armament" is implied torpedo tubes and torpedoes, which constitute the only offensive armament of a submarine when the guns are not used for shelling merchant ships.

At the time of the entrance of the United States into the present conflict as a belligerent, there was much speculation on the part of the public as to whether German submarines would or could operate as raiders on the Atlantic seaboard and harass American shipping bound for Europe. The fact that it has not been attempted may very well be attributed to a decision on the part of the German Government not to disperse or dissipate any part of their submarine fleet in what could hardly be more than a demonstration for moral effect, to the detriment of the major operation of blockading the coasts of the



An Austrian Submarine

British Isles. That it is entirely feasible, however, and can be done, and may be done, at any moment that it suits the policy of Germany to do so, may well be taken for granted, if it has not been already demonstrated by the exploits of the U-53 and the *Deutschland* before the United States became a belligerent. Of course, the closing of American ports and the impossibility of obtaining supplies in American harbours would somewhat alter the circumstances of the situation, but not sufficiently to make such a campaign impossible. Without having recourse to the ballast tanks for carrying reserve fuel oil, all of the larger German submarines are capable of evading the British blockade and crossing the Atlantic, precisely as was done by the U-53. The only problem would be the one of supplying vessels operating on the Atlantic coast with a suitable base of operations from which to obtain the necessary fuel, torpedoes, and other supplies. It is apparent that this base of operations would have to be on this side of the Atlantic as no effective campaign could be conducted were frequent trips back and forth to Germany necessary.

The so-called commercial submarines of the

*Deutschland* type had a cargo carrying capacity of about 400 tons, and their ability to evade the blockade and cross the Atlantic has also been demonstrated. At the time the *Deutschland* and a number of other vessels of the same type were built, it was significantly suggested that the limited company so ostentatiously organised for the purpose of running this service as a commercial proposition, merely served as a cloak to mask an experiment conducted by order of the German Government for the purpose of determining the feasibility of such vessels as mother ships for squadrons of submarines that might be called upon to operate at long distances from their home ports. One of these cargo carriers loaded with submarine supplies could easily carry a sufficient quantity to provide half a dozen submarines for a couple of months, especially as the tactics of the submarines operating on this coast would be to lie in wait off the entrances to the principal harbours in the well-known routes followed by shipping, and in such a formation that a ship could hardly hope to get through without coming within torpedo range of one of the blockading submarines. Such tactics would not make very great

demands upon their supply of fuel oil, which would lengthen the time they could operate without having to re-fuel.

In undertaking a campaign of this kind, the so-called commercial submarines laden with submarine supplies would first be sent out to take up pre-determined stations on the bottom of the sea at some convenient point off the Atlantic sea-board. Their position would, of course, be accurately known by the submarines designated to operate on this coast. When a new supply of torpedoes or fuel was required by any of the submarines, it would communicate that fact to the mother ship lying on the bottom of the sea by means of the submarine signal. The mother ship would then come to the surface and the two vessels would meet at some pre-arranged spot, probably during the night, and a couple of hours would more than suffice to re-fill the fuel tanks. The principal difficulty would be the transference of torpedoes from the mother ship to the submarine in case the weather was rough. It might be necessary to wait for several days for weather calm enough to permit this operation to be effected without damaging the torpedoes. For that reason it is probable that such

a campaign would only be conducted in the summer time. The east coast of the United States is quite congenial for operations conducted in this way, for there are many miles of coast where the water is not over 200 feet in depth, where the mother ship could lie comfortably at the bottom, absolutely immune from any danger of observation or attack. The only chance of detecting and destroying them would be on the occasion of their rising to the surface to refresh the air or to transfer supplies. This method has not been attempted in the operations against Great Britain as it is much more economical and simpler to establish bases among the many uninhabited islands off the west coast of Scotland, or to employ a merchant ship masquerading under a neutral flag. Moreover, their home ports of Wilhelmshaven and Zeebrugge, which latter has been converted into a powerful submarine base, are not so remote from their present theatre of operations as to justify the use of submarine mother ships. Net entanglements for the protection of American harbours, such as have been used so effectively by the British in closing the English Channel, would not fulfil the same function in this case, as the submar-

ines would make no efforts to enter the harbours, but would merely wait outside for ships that would eventually have to come out. A more active system of defence, similar to the methods now being employed by the Allies to hunt down and destroy enemy submarines off the west coast of the British Isles, would have to be applied in this case also. At this juncture it may well be asked, "If a campaign of this kind against shipping leaving American harbours can so easily be conducted, why has it not been attempted?" Although only the German Navy Department can authoritatively answer this question, all the evidence shows that the German authorities, by their refusal to declare war on the United States or to admit that a state of war exists, in fact, by their very failure to specifically attack shipping leaving American ports, have determined to avoid any act that might unnecessarily antagonise American public opinion, further than has already been done, for their experience with England has demonstrated that intensified aggression has merely served to arouse the spirit of enthusiasm of the individual and has enormously strengthened the power, potential and actual,

of the Government so attacked. When, in course of time, events have proven that such restraint has not prevented the American Governmen from calmly proceeding with the organisation of a formidable army, when, in other words, the German Government have become convinced that their hesitation to overtly attack specific American interests has had no influence in mitigating the effect of America's participation in the war against them and that they have nothing to lose from ruthlessness, the circumstances will then be favourable for a reconsideration of their war policy towards this country. Without the slightest attempt at prognostication, this would constitute the logical moment for initiating an aggressive and ruthless submarine campaign against this country and for blockading American ports. Such a change in policy for obvious reasons is not likely to take effect, if at all, before the spring of 1918.

We have considered the theoretical relation of the submarine to naval policy in general and the application of theory to circumstances under the different conditions of peace and war in Germany. It may now be of interest to consider briefly what other nations, and especially

the United States, have done in implementing theory with reality.

Among the European powers, France was the first to experiment on a serious scale and to develop this branch of her naval service to an impressive extent. At the outbreak of war she had in commission about fifty submarines of various sorts and sizes, ranging from the most modern through all chromatic degrees of the scale down to those bordering on the scrap heap. The French Submarine Service has frequently been rather sarcastically and probably unjustly referred to as a "Museum." This criticism is undoubtedly due to the fact that navally speaking or, more properly, submarinely speaking—France has not known her own mind and has most illogically and inconsistently jumped from one extreme point of view to another, at one time considering maximum size as a *sine qua non;* at another the smallest possible size combined with a staggering armament, again, high surface speed, at the expense of all other qualities, with the inevitable heterogeneous results of no logical settled policy. The French Navy has extensively adopted the Drzwiecki torpedo launching apparatus for the

purpose of obtaining the maximum armament for a given displacement. This mechanism, the invention of a Russian engineer, consists of a light framework bracket outside the vessel which supports the torpedo in a longitudinal position alongside the hull. When the torpedo is to be fired, the bracket is swung out by a mechanical device inside the boat and the torpedo is automatically released when the proper angle has been reached.

A relatively small submarine can carry 8 of these launching devices, four on each broadside. As they are above water when the vessel is on the surface they can only be used submerged. This, in itself is not a serious disadvantage, but the reloading of the device can only be effected with safety in harbour.

Adjustment of the torpedo is exceedingly difficult, and owing to the fact that the firing takes place while swinging through a horizontal arc, inaccuracy of fire is notorious. The apparent superiority in armament obtained by the use of this device is therefore more nominal than real. The only other navy to make use of this invention is the Russian, in which case nationalism has probably played a greater rôle than

utility. The construction of submarines in France has been limited to the Government Navy Yards to the exclusion of private participation and competition with the inevitable result of technical and engineering stagnation. Without the spur and stimulation of competition, the highest technical development is impossible.

England looked on until 1902, for the introduction of the submarine was not a pleasing innovation to the supreme naval power. However, its defensive possibilities could not be overlooked; moreover the utilisation of submarines for coast and harbour defence would release a certain number of ships for what the naval officers deemed more important work, so a sample lot of 5 boats of the *Holland* type was ordered, since which time gradual and conservative development along the same general lines found England at the outbreak of the war with about 80 submarines in commission, practically all of which were under 900 tons' displacement, coming therefore in the classification of coast defence type.

England has gone to the opposite extreme, in comparison with France, and has at least

avoided the "museum" evil. Not, however, without the sacrifice of a certain degree of technical development. One firm has had, until recently, a practical monopoly with of course the usual tendency to inertia in an engineering sense, but the progress that has been made has been along systematic and consistent lines, so that if radical results have not been achieved, serious blunders have at least been avoided.

Austria, having no national genius to supply her with a submarine type of her own, contracted in 1907 for six boats, two of each of the *Holland, Lake* and *Krupp* types, which were literally and avowedly "sample" copies. Why one of each would not have served the same purpose has never been satisfactorily explained. Before these vessels were completed, however, the Austrian Foreign Office became converted to "Deutschtum" so that the following contract for six vessels was given to Krupp and construction in Austria was not even required. These six last vessels were barely completed when war broke out.

Italy has always been faithful, with one political exception, to her national designer, and the

twenty submarines built and building when the war broke out were all constructed by the Fiat Company from the designs of Laurenti.

When one comes to Russia, many considerations played a part with the old régime in determining its course of naval policy besides the necessities of naval strategy or political expediencies. It was open gossip in Petrograd before the war that the Czar had given instructions to place an order for a Russian warship in Germany because on one of their junketing excursions together in the Baltic on the Czar's yacht, his Germanic guest had made it pleasantly and agreeably impossible for him to do otherwise and it is more than likely that many submarines have been built for even less potent naval reasons. Just how many submarines Russia had in commission at the outbreak of hostilities, was probably uncertain even to some of their own Admiralty officials and their type was equally vague. There were some relics of the Russo-Japanese War, the fruits of a frenzied and belated scramble to secure anything that could be considered militarily useful.

It would require an intimate knowledge of the personal relations of Ministers, their wives and

other men's wives and other men, intricate and changeable as a telephone switchboard, to trace the intrigues and motives, the cause and effect that materialised in Russia's Submarine Service. It will suffice for our present purposes to say that Russia had a varied assortment of about 45 submarines nominally in service when war was declared.

Holland is one of the few, among the smaller powers, with a definite submarine policy. The submarines in commission are sharply divided into two classes; home defence, which do not exceed, 200 tons of displacement and of which 7 are built, and Colonial defence of 800 tons' displacement and also 7 in number. It is generally conceded that a proper defence of the Dutch Colonies necessitates a fleet of from 50 to 60 submarines of not less than 800 tons' displacement. The disparity between 50 to 60 required and 7 actually built expresses the difference between mental realisation and financial limitations.

Holland, however, is not the only one among the smaller powers obliged to trim her naval sails to suit pecuniary exigencies. It will not be necessary to enumerate individually the

other European Powers, all of which, if they possess any seaboard at all, had at least the rudiments of a submarine service when war broke out with the exception of Bulgaria and Roumania. These two countries laboured under the serious disability on the one hand of insufficient shipbuilding resources to build at home, and on the other hand, the impossibility, because of international agreements, of bringing any foreign-built war vessel through the Dardanelles into the Black Sea.

In order to find a satisfactory solution and permit these countries to fulfil their "legitimate naval aspirations," the author had occasion to study this problem to the point of investigating the radius of the curves and the dimensions of the tunnels on the railways running from Central Europe to Galatz and Varna, but this solution of the difficulty so limited the size of the vessels that it was considered impracticable, and war imperiously brought the matter to a standstill.

With the exception of Denmark (which possessed a fleet of 15 submarines, the majority of which were built from the author's designs), and Belgium, which had no navy at all, and with

the two further exceptions above noted, none of the smaller powers possessed less than two nor more than eight boats. As none of these countries could lay claim to a native designer, their choice had to be made among the types which the greater powers had already adopted.

As the smaller Powers frequently required a loan to permit the expansion of their naval and military establishments and the granting of the loan almost invariably imposed the condition of spending the money in the country supplying the funds, the choice of submarine type on the part of many of the smaller Powers has not been as free and untrammeled as it may have appeared.

South America has not ventured very far as yet on the under-water road. What has been accomplished more nearly resembles a competition in inactivity than anything else.

Peru, for and in consideration of certain financial privileges conferred by the French Government, possesses two submarines of the Laubeuf type. The Brazilian Navy has a submarine flotilla of 3 Fiat-Laurenti boats, and Chile had an incipient squadron of 2 Holland boats, until the circumstances of war caused

them to be sold to Canada before they were ready for delivery to Chile. Argentina has waited watchfully and the other South American countries have waited, whatever else they may have done.

The only Oriental Power to hazard the risks and privileges that accompany the possession of a submarine fleet is Japan. Just prior to the Russo-Japanese war, the Japanese Government placed a trial order for 6 boats in the United States.

These vessels were erected in this country, then taken apart and shipped to Japan for re-erection and completion. Since that time Japan has purchased several submarines from England, two from France and has constructed additional vessels in Japanese yards. At the outbreak of war, the Japanese fleet numbered about 15 vessels, but their policy has been about as indeterminate as their choice of type. It is undoubtedly true that Japan has devoted more thought to the development of her fleet of capital ships during the last decade than to the lesser arms of the service and the reason is not far to seek.

What has the United States done in regard

has been realised, however, and has been met by commencing in 1916 the construction of an experimental vessel of 1100 tons surface displacement with a contract speed of 19 knots. This has since been augmented by contracting for the construction of 2 similar vessels and 3 others of 800 tons displacement. These last are experimental in character, for they are all of different designs.

The reversion to a smaller type of only 800 tons, after having commenced the construction of 1100 ton fleet submarines, is probably due to a desire on the part of the United States Government to acquire experience with a size of vessel which is practically universal in the navies of all the great powers with the single exception of the United States Navy.

It has been stated that the *Holland* type had a practical monopoly in this country. The only break in the record is one boat of the *Fiat* type, built by Cramp, and several boats of the *Lake* type.

Although progress and development in this country has been systematic, logical and consistent, the same price has necessarily been paid for it, as in England where a single firm has also

had the virtual monopoly until recent years.

As in other countries, the events of this war have definitely assured the future of the submarine in this country, but if a really efficacious number is to be maintained, it will have to be realised here as elsewhere that a submarine is not immortal, that gradual small increments will not produce the requisite number by a process of accumulation like a savings bank account. There is a counter process of deterioration going on which must at least be exceeded, to produce any increase at all, for the average life of a submarine is not over fifteen years.

In Holland, for example, where an appropriation averaging 3 boats per year for Colonial defence has been made, the desired and required number of 60 can never be attained until the rate is accelerated. That the situation created by the pressure of actual war is not the proper atmosphere and time for commencing such expansion, will be amply evident to those who have read the section relating to time required for construction, all that has been said and read about pouring submarines in a mould, to the contrary notwithstanding.

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